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An Outline of the Tertiary Geology of Burma.

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I. Introduction.

FOR more than a quarter of a century the Tertiary geology of Burma has been the subject of investigation from the point of view of the petroleum resources of the country. A vast amount of detailed information must be stored up in the private files of the various oil companies operating in Burma, and it is a source of continual regret to the geologist that at least some of this information—much of which has great scientific but little commercial value—cannot be made public. Although there exists Dr. Noetling's important but misleading monograph on the supposed "Miocene Fauna of Burma", published in the *Palæontographia Indica*, 1901, it is only within the last decade that the Tertiary stratigraphy has been seriously considered from a palæontological standpoint, and for this progress the officers of the Geological Survey of India are almost entirely responsible. In this direction immensely valuable results have already been obtained, though the study is scarcely more than in its infancy.

The object of the present paper is to bring together in the form of a brief summary the results of previously published investigation, to fill in at least a few of the gaps by including the results of the writer's observations in certain extensive areas in the Chindwin Districts and elsewhere in Burma, but more especially to apply certain important principles which have been deduced as a result of the study of the Tertiary deposits of North-Western Europe. A summary of these principles and their application to the classification of the Eocene beds of the Anglo-Franco-Belgian Basin has been published in the Geological Magazine.[1]

[1] Stamp, Geol. Mag., Vol. LVIII, 1921, pp. 108–12.

II. Physical Geography of Burma.

Burma falls very simply into well-marked natural regions, the physiography of which is controlled mainly by the geology, whilst minor subdivisions can be made on a climatological basis. The main divisions are as follows (see Fig. 1):—

(1) The Shan Plateau,[1] occupying the whole of the east of the country. It is a region of highly folded Pre-Palæozoic, Palæozoic, and early Mesozoic rocks, the folds running mainly north and south. Bounding this region on the west is a great line of dislocation which has for many hundreds of miles a roughly north and south direction. This may be termed the Shan Boundary Fault, and the change from the central lowlands to the plateau is at once abrupt and sharply defined. Immediately to the east of the fault there is usually a strip of crystalline rocks. The Shan Plateau is on an average between 3,000 and 4,000 feet above sea-level, and is continuous with the plateau of Yun-nan. As a contrast to the fine highland scenery of the Palæozoic rocks, well known to the frequenters of Burma's favourite hill-stations—Maymyo and Kalaw—there are broad, level tracts marking the sites of lake basins filled with late Tertiary or Pleistocene deposits. These basins are of some importance as yielding brown coal [2] (as in the coalfields of Lashio, Namma, etc.), and in one case oil-shale. Some of the basins are still occupied by lakes (as Lake Inlè). It may be noted, *en passant*, that the coals of the Shan States belong to two distinct groups; firstly, the Late Tertiary or Pleistocene [3] lignites occurring as almost horizontal beds in the basins already mentioned; secondly, the humic coals of early Jurassic age occurring in strata which have been subjected to the same intense folding as the Palæozoic sediments. The coals of Kalaw (Loi-an) belong to the latter group.[4] It is not the purpose of this note to discuss the Shan Plateau or even its Tertiary basins; the important points to notice are:—

(*a*) the main folding is post-early Jurassic and pre-late Tertiary,

(*b*) the absence of early Tertiary deposits which are of such enormous thickness in the central Tertiary region make it almost certain that the main folding and the initiation of the Shan Boundary Fault are pre-Tertiary,

(*c*) from the but slightly tilted late Tertiary deposits in the lake basins, the Shan Plateau must have played the part of a "stable block" during the late Pliocene folding of the main Tertiary region of Burma.

(2) The Central Tertiary Belt, a strip of country 500 or 600 miles from north to south and averaging 130 miles wide, bounded by the

[1] La Touche, "Geology of the Northern Shan States": *Mem. Geol. Surv. India*, vol. xxxix, pt. ii, 1913; Middlemiss (part of Southern Shan States), *Gen. Rep. Geol. Surv. India* for 1899–1900.

[2] La Touche and Simpson, *Rec. Geol. Surv. India*, vol. xxxiii, pt. ii, 1906, pp. 117 et seq.

[3] Annandale, *Rec. G.S.I.*, vol. l, pt. iii, 1919, pp. 50–64.

[4] Unpublished information. The writer has collected Jurassic plants and the same conclusions as to age have been reached independently by other observers recently.

Shan Plateau on the east and by the great fold-range of the Arakan Yoma on the west. Whilst the boundary is sharply defined on the east, on the west the Tertiary region rises somewhat gradually from the Irrawaddy Valley to the foot-hills of the Arakans. It is by

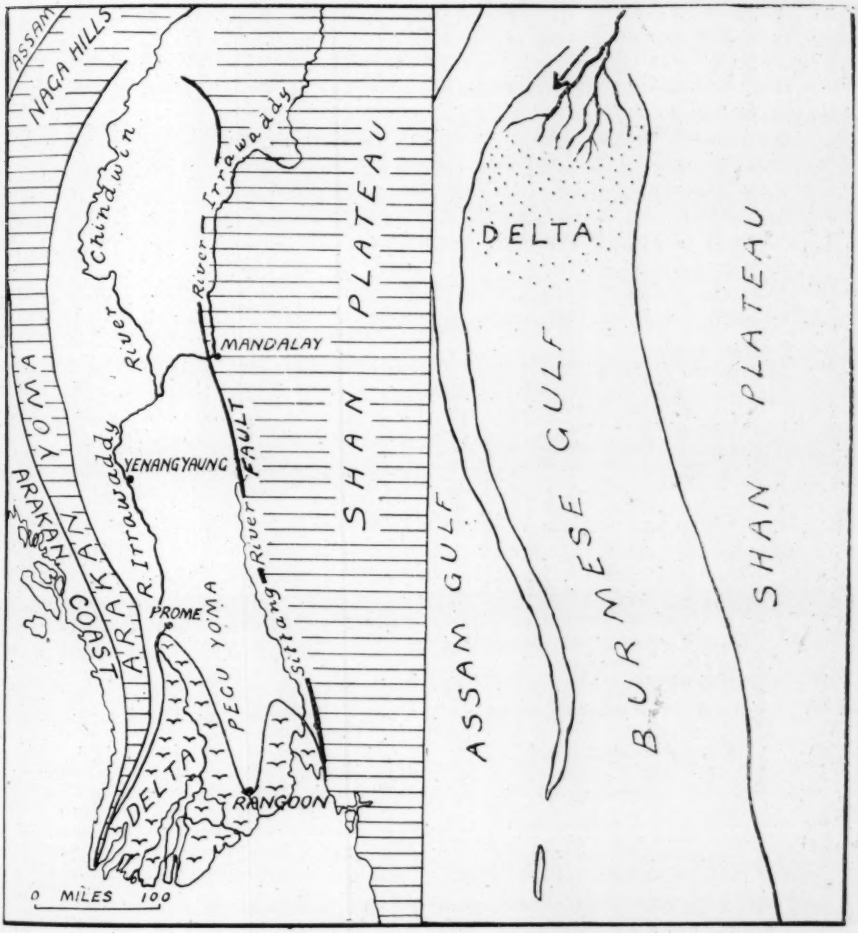


FIG. 1.—The Natural Regions of Burma.—L. D. S.

FIG. 2.—The Geography of Early Tertiary Times.—L. D. S.

no means a monotonous tract. Its southern half is occupied by the valleys of the Irrawaddy and Sittang rivers on the west and east respectively, separated by the low, but somewhat inaccessible range of the Pegu Yoma. In the south one may distinguish as a separate region the great flat delta of the Irrawaddy, dropping very

gradually to the shallow waters of the Gulf of Martaban. The northern half of the Tertiary region is occupied by the valleys of the Chindwin and the Irrawaddy on the west and east respectively. Climatologically the Tertiary belt, being on the lee of the Arakan Yoma and protected from the rain-bearing South-West Monsoon, enjoys a dry and healthy climate. The rainfall is lowest—about 20 inches—in the latitude of Yenangyaung, giving rise to a tract of semi-desert. The rainfall increases to the north and to the south, as well as to the west as one approaches the Arakan Yoma, and the semi-desert with its thorny shrubs, Euphorbias, Cacti, and stiff-looking Toddy Palms passes gradually into shrubland and then into Monsoon Forest of teak-trees. Elevation and soil play an important part in the ecology of the country.

(3) The Fold Range of the Arakan Yoma forms an important barrier bounding the Tertiary region on the west. It stretches from the Naga Hills of Assam in the north to the extreme south-western point of Burma in Cape Negrais, being continued by the rugged islands of the Andaman and Nicobar groups into Sumatra (Barissan Range) and Java. Topographically the range is still largely unknown, large areas being unmapped in detail, whilst geological knowledge depends on a few incomplete traverses. Throughout the length of the range there is really no line of transverse communication—not even a well-known forest track, and large areas are uninhabited. As knowledge of their geology slowly accumulates it becomes more and more certain that the structure of the Arakan Yomas is that of a complex anticlinorium. The core consists of pre-Tertiary rocks [1] (including at least Trias [2] and Cretaceous—Cenomanian [3] and possibly Danian [4]). The core is flanked on either side by Tertiary rocks. Certain facts of considerable importance disengage themselves from the scattered scraps of available information :—

(*a*) at or near the base of the Tertiary deposits on the eastern side there is a very thick basal conglomerate (Paung-gyi Conglomerate) which is Lower Eocene in age,

(*b*) despite the fact that the Eocene deposits take part in the folding and have been ridged into steep-limbed anticlines or overfolds (see Fig. 6), there is always a marked change from the comparatively unaltered Tertiary to the cleaved and puckered Cretaceous and earlier rocks,

(*c*) there is a notable difference between the Tertiary deposits on the two sides of the Arakan Yoma.

One is forced to the conclusion that the great fold of the Arakan Yoma was initiated in late Cretaceous times, and even as early as the Eocene constituted a barrier between the areas of deposition on

[1] Axial Group, Maii Group, and part of the Negrais Group of Theobald, *Mem. G.S.I.*, vol. x, pt. ii, 1874. This paper of Theobald on the "Geology of Pegu", or Lower Burma, laid the real foundation of the study of the geology of Burma, and is still largely followed.

[2] *Rec. G.S.I.*, vol. xxxiv, 1906, p. 134.

[3] *Mem. G.S.I.*, vol. x, 1874, p. 123 (311).

[4] *Rec. G.S.I.*, vol. xxxv, pt. ii, 1907, p. 119.

the east and west respectively.[1] In several cases where it has been examined the junction between the Tertiary and pre-Tertiary rocks on the eastern side of the Arakan Yoma is faulted. It is quite possible that a great line of dislocation exists between the two —between the Arakan Yoma and its foot-hills—and if this were the case the Tertiary region of Burma would in reality be a typical rift valley.

(4) Bordering the Arakan Yoma on the west is a strip of wild, rugged country, deeply intersected by bays and gulfs, and fringed by islands forming the Arakan coast. It consists of Tertiary rocks, which belong to the Assam Gulf of deposition as distinct from the Burma or Pegu Gulf on the other side of the Arakan Yoma.[2]

III. The Geography of the Tertiary Period in Burma.

No apology is tendered for attempting to consider the Tertiary geology of Burma from the point of view afforded by a reconstruction of the geography of the period. The reconstruction is based, of course, on detailed study in field and laboratory, a great part of the information being now available in published form. Despite the lack of knowledge concerning many parts of Burma, this palæogeographical picture may be considered as reasonably correct and it helps to explain many facts otherwise difficult of interpretation. More important, perhaps, it supplies a simple means of visualizing and memorizing a mass of facts—an advantage not to be ignored in attempting a comprehensive view of the world's stratigraphy.

As already pointed out, the main folding of the Shan Plateau as well as the earlier stages of the uprise of the Arakan Yoma took place in pre-Tertiary, probably in late Cretaceous, times. There is every reason to believe that the former was a land mass from earliest Tertiary times and that the latter formed a narrow ridge separating two arms of the sea—the Gulfs of Assam and Burma. The line of the Arakan Yoma is continued through the Andaman and Nicobar Islands to Sumatra and Java, but most probably this line was breached by the sea throughout the Tertiary period, just as it is at the present day. The history of the Tertiary period in Burma is largely that of the infilling of the Burmese Gulf—a great geosyncline—by sediments both continental and marine. Flowing into the gulf from the north there were one or more rivers which poured in huge masses of sediment. The Irrawaddy of the present day may be looked upon as the remnant of this great Tertiary river-system (see Fig. 2).

There has been, generally speaking, a gradual movement south-

[1] Cotter, "The Geotectonics of the Tertiary Irrawaddy Basin": *Journ. and Proc. Asiatic Soc. Bengal*, N.S., vol. xiv, 1918, pp. 409–20, especially p. 412; Vredenburg, *Rec. G.S.I.*, vol. li, pt. iii, 1921, p. 302.

[2] Pascoe, "The Oil Fields of Burma": *Mem. G.S.I.*, vol. xli, pt. i, 1912, pp. 179–99; Pascoe, "Oil Occurrences in Assam and Bengal": *Mem. G.S.I.*, vol. xli, pt. ii, 1914.

wards of deltaic conditions from the Eocene to the present and a consequent retreat of the sea towards the south.[1] It follows that :

(*a*) the Tertiary succession is predominantly marine in the south and mainly continental in the north,

(*b*) each horizon can be traced laterally from marine through deltaic into fluviatile or æolian deposits as one goes northwards,

(*c*) there is, on the whole, a tendency for continental conditions to move southwards as one ascends in the succession. The continental type of Pliocene (Irrawadian) is the most widely spread of all the continental deposits.

Certain other important factors must, however, be considered. Throughout the Tertiary period there seem to have been movements of folding and uplift along the line of the Arakan Yomas, culminating in the great folding movements which affect all the Tertiary deposits of Burma and which took place towards the end of the Pliocene. The Burma Gulf commenced as a geosyncline, and, like all geosynclines, has undergone " buckling " and deepening at intervals. The principal effects of this intermittent deepening have been to allow the accumulation of a vast thickness of sediment and to cause the return of marine conditions northwards. Consequently, although there has been a general retreat of the sea to the south, there is evidence of periodic marine invasions northwards. These marine invasions are marked by wedge-shaped masses of marine strata in the midst of the beds of continental type. This is well seen in the case of the marine Yaw Series of Upper Burma. In other words, there is a series of cycles of sedimentation. An effect of the " buckling " is seen in the overlap of certain beds when traced from the margins towards the centre of the basin. That is to say that normally two beds are in direct and conformable superposition; locally the lower bed may be absent and the higher bed may be seen resting on some older strata owing to the effect of slight folding and consequent denudation just prior to the deposition of the higher bed. It is not possible to point to any great unconformities amongst the Tertiary strata of Burma, though much has been written on their occurrence or otherwise. The observed cases fall into two groups :—

(*a*) " ravinements " such as occur almost invariably at the base of Cycles of Sedimentation.[2] Examples: the base of the Yaw Stage in the Lower Chindwin District,[3] and probably also the base of the Irrawadian in the Oilfields of Minbu, Yenangyaung, etc. The intra-formational " unconformities " frequently observed in the Pegu System belong to this class,

(*b*) local unconformities due to the denudation of minor folds produced as a result of the " buckling " of the floor of the geosyncline during the Tertiary period. A good example is seen in the Myaing region, where the Irrawadian rests directly on the Pondaung Sandstone.[4]

[1] Cotter, *Journ. and Proc. Asiatic Soc. Bengal*, N.S., vol. xiv, 1918, p. 414.

[2] Stamp, GEOL. MAG., Vol. LVIII, 1921, p. 109.

[3] For details see Stamp, " The Geology of Part of the Pondaung Range, Burma ", *Trans. Mining and Geol. Inst. India*, vol. xvii, 1922.

[4] *Geol. Surv. India*, 1 in. map, Sheet 84K./14, geologically coloured.

An extreme case, and one of great interest, of the effect of the minor folding in the floor of the geosyncline is seen around Shinmadaung near Pakokku.[1] Here, in the very midst of the Tertiary Belt, a ridge of the pre-Cambrian gneisses, which must evidently form the floor of the old gulf, appears at the surface as a result of folding and faulting. The exact relationship with the surrounding Pegu rocks is uncertain, but the lowest Pegu (Shwezetaw Sandstones) appear to rest directly on the gneiss. It may be noted that this locality is along the line of Tertiary volcanoes which passes through the midst of the Tertiary Belt. Around Shinmadaung igneous rocks are found interbedded with Pegu and probably with Irrawadian sediments.

IV. The Tertiary Succession and its Classification.

From what has already been said it follows that the Tertiary succession in Lower Burma is very different from that in Upper Burma. A failure to recognize the importance of lateral variation and the wedging out of marine beds when followed northwards has caused considerable confusion and invalidates much that has been written on the Tertiary geology of Burma. The progress which has been made in this respect within the last few years is largely due to the work of Dr. G. de P. Cotter.

It may be said at once—

(*a*) that very little is known of the succession in the Sittang Valley, that is to say, on the eastern side of the Pegu Yoma,

(*b*) that the Eocene strata are very imperfectly known,

(*c*) that many points in the correlation of the succession in Upper and Lower Burma are still uncertain.

It is found, however, that most of the principles of the cycle of sedimentation can be applied on a large scale to the interpretation of the Burmese sequence. An attempt has been made to express the classification and correlation in the form of a diagram (Fig. 3). The diagram also indicates roughly the lithology of the beds. Under "continental" are included æolian, lacustrine, fluviatile, and some brackish water deposits.[2]

Eocene.

1. *Southern Region* (Nicobar and Andaman Islands and Lower Burma).

In the Andaman Islands[3] the Eocene is represented by a series of conglomerates and sandstones resting unconformably on, and containing pebbles derived from, the underlying rocks, which are probably Cretaceous and comparable with the Axial Group of the Arakan Yoma. In passing it may be noted that the deepest water in Eocene times lay to the south and the deposits of this age are represented by limestones in parts of Sumatra and Java.

[1] Vredenburg, *Rec. G.S.I.*, vol. liii, 1921 (1922), p. 365.

[2] Most of the places mentioned in the following account will be found on the maps, figs. 4 and 5.

[3] Tipper, "The Geology of the Andaman Islands with references to the Nicobars": *Mem. G.S.I.*, vol. xxxv, pt. iv, 1911.

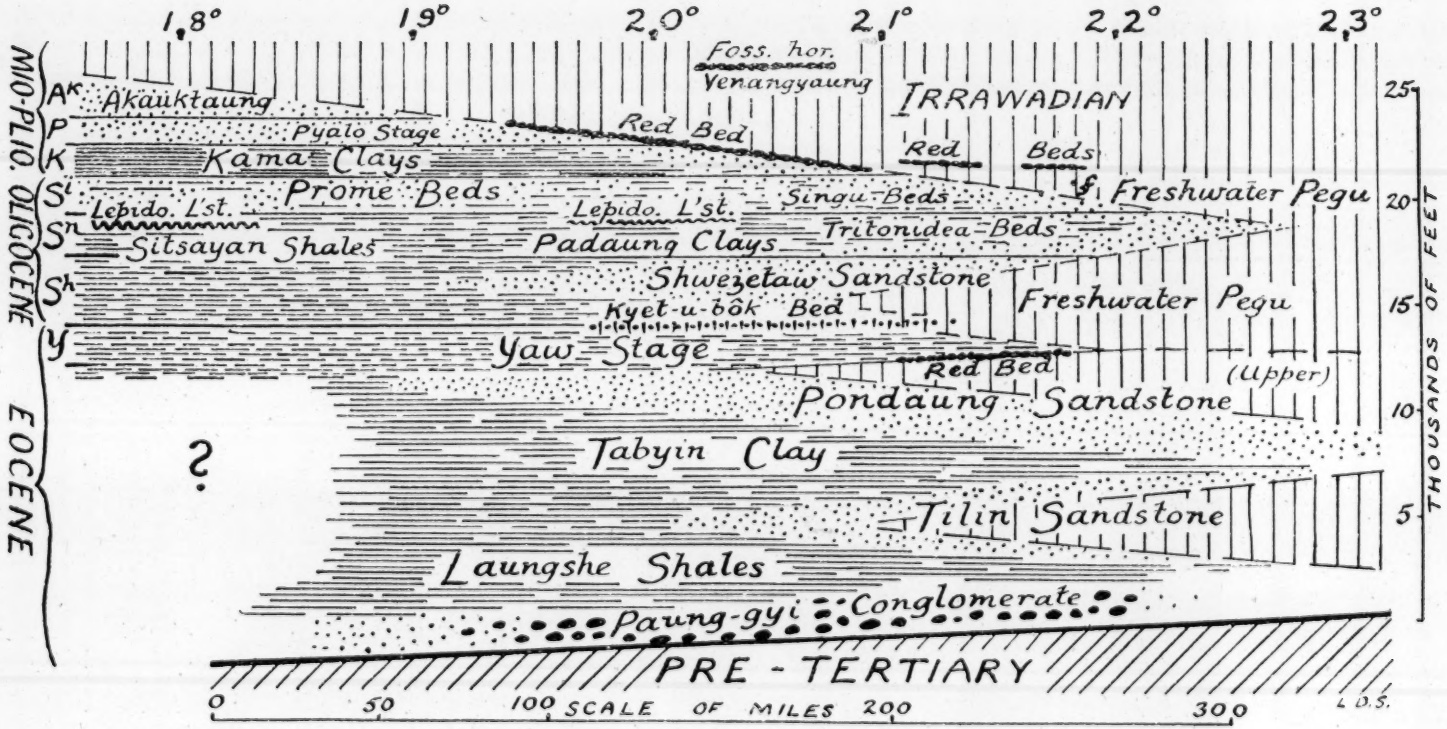


FIG. 3.—Diagram showing the relationships of the Tertiary Rocks of the Burmese Gulf.—L. D. S.

Little is known of the Eocene rocks [1] of Lower Burma (Henzada and Prome Districts). They consist mainly of unfossiliferous shales and sandstones much disturbed by faulting. The junction with the pre-Tertiary rocks appears to be invariably faulted.[2]

2. *Northern Region* (Upper Burma).

Here the Eocene rocks are of greater interest and have been studied in some detail, especially with regard to the higher beds. The succession is :—

5. Yaw Stage (marine shales).
4. Pondaung Sandstones.
3. Tabyin Clays.
2. Tilin Sandstone.
1. Laungshe Shales with Paung-gyi Conglomerate at or near the base.

Paung-gyi or Swelegyin Conglomerate.—A typical basal conglomerate from 2,000 to 4,000 feet thick. The contrast between the folded but comparatively unaltered conglomerate and the underlying cleaved and folded shales or phyllites (Kanpetlet Schists, etc.) has already been noted. The pebbles in the conglomerate seem to consist very largely of fragments of these rocks together with a few gneisses of more distant origin.

Laungshe Shales.—Possibly from 9,000 to 12,000 feet in thickness. The fauna of these beds has not yet been studied, but seems to include several forms of late Cretaceous aspect, possibly survivals in the early Eocene gulf. The most abundant fossil is a large *Operculina*.

Tilin Sandstone.—It is probable that this arenaceous group, marine in the south, becomes brackish or freshwater northwards. It is certainly much thinner in the south, and cannot be traced as a separate division to the south of latitude 20° 15′. This attenuation from an estimated thickness of up to 5,000 feet in the north to nothing in the south probably accounts for the huge thickness claimed for the Laungshe Shales in the south.

Tabyin Clays.—A group of greenish, somewhat rubbly shales, up to 5,000 feet in thickness. The most interesting fossil is *Nummulites vredenburgi* Prever. In the south other nummulites, some of large size, are found, apparently at this horizon or slightly higher (Minbu district). North of latitude 21° 45′ the writer did not succeed in finding any nummulites or other marine fossils, but numerous thin seams of coal occur in the higher part. The coals of the Upper Chindwin appear to belong to this and to the succeeding division.

[1] Roughly the "Nummulitics" of Theobald (op. cit.), but he mistook certain limestone bands with *Lepidocyclina* which occur in the lower part of the Pegu for Nummulitic Limestones, and so has drawn the upper limit of the "Nummulitics" too high in several cases. Noetling (*Pal. Ind.*, N.S., vol. i, p. 6) intended to have substituted his own terms "Bassein" and "Chin" Divisions for Theobald's "Nummulitics" and "Axials" respectively, but he made serious errors in definition which invalidates his classification (see Pascoe, *Mem. G.S.I.*, vol. xl, pt. i, 1912, p. 14).

[2] Theobald, op. cit., p. 102 (290); Stuart, *Rec. G.S.I.*, vol. xli, pt. 4, 1912, pp. 240–65, and pls. 22–4.

Pondaung Sandstone.—A very interesting series of deposits. The lower part comprises beds of greenish sandstone (weathering yellow), with bands of conglomerate and greenish shale and passes down quite gradually into the Tabyin Clays below (1 in. map, sheet 84 K./5). Fossils here (latitude 21° 50′ to 22° 45′) are scarce, but include *Arca*, *Cardita*, and other marine forms. Going upwards in the series the Pondaung Sandstones exhibit a gradual change from marine to brackish and finally to freshwater and land conditions. Plant remains (wood) occur throughout; in the lower part the wood is carbonized, higher up partly carbonized and partly silicified, whilst in the highest part it is always silicified. It should be mentioned that silicified wood is highly characteristic of continental deposits in Burma. As one passes northwards (as from latitude 21° 45′ to 23° 30′) the upper continental beds thicken at the expense of the lower marine. The most striking members of the continental facies are beds of clay—purplish, pale greenish, or mottled—with abundant vertebrate remains indicating their formation in freshwater lagoons.[1] The remains include mammals (*Anthracotherium*, *Anthracohyus*, *Metamynodon* ? etc.), crocodiles (*Crocodilus*), and huge turtles. From about latitude 22° 0′ to 22° 30′ the highest bed is a "Red Bed" or layer of laterite denoting terrestial conditions. To the south the whole of the Pondaung Sandstones become more marine, the mottled or purplish clays are not found much to the south of latitude 20° 30′, and oysters[2] (*Alectryonia noetlingi*) are here abundant. Large nummulites are common from 20° 5′ southwards. The group is as thick as 6,500 feet in latitude 22° 5′.

Yaw Stage.—A series of shaley clays with an interesting fauna which has been described in part.[3] The series is essentially a marine one, and fossils include *Nummulites yawensis* Cotter,[4] *Velates orientalis* Vred. (near *V. schmideliana* Chemn.)—the latter especially in the upper part—large *Ampullinæ* (*A.* cf. *grossa* Desh.), etc. The stage is typically developed about latitude 21° 30′ longitude 94° 20′ E.; northwards marine fossils gradually become scarcer and stunted, and the deposits wedge out, being absent in latitude 22° 45′. Owing probably to the proximity of the western shore-line, the deposits are very sandy about latitude 21° 5′, but again become of deeper-water type in the Ngapè-Yenanma area (latitude 19° 50′ to 20° 5′). Eastwards in the Myaing district (latitude 21° 37′, longitude 94° 52′) the series is again of shallow-water type, possibly due to the nearness of the ridge of ancient rocks of Shinmadaung mentioned above. In the north the base of the Yaw

[1] For details on all these points see Stamp, "Geology of Part of the Pondaung Range."

[2] Pilgrim and Cotter, *Rec. G.S.I.*, vol. xlvii, pt. i, pp. 42–77, pls. 1–6.

[3] Cotter, "The Lamellibranchiata of the Eocene of Burma": *Palæontologia Indica*, 1922 (in the press).

[4] Cotter, "On the Value of Nummulites as Zone-fossils, with a Description of some Burmese Species": *Rec. G.S.I.*, vol. xliv, pt. i, 1914.

Stage is marked by interesting bone-beds, whilst conglomeratic bands with fish remains occur throughout. With regard to the upper limit, northwards from 21° 45′ the series passes up gradually into the overlying "Freshwater Pegu"; whilst in the south it would appear to be well defined by a bed which the writer prefers to regard as the base of the Pegu. The latter bed, described below, has been traced at intervals for 100 miles, though it should be mentioned in fairness that general agreement as to the identity of the bed throughout has not yet been reached.

Post-Eocene (Pegu-Irrawadian).

As being the main petroliferous horizon the Pegu has been studied in great detail, but it is only very recently that anything like a clear conception of the deposits as a whole has been obtained, and much remains to be done. In this respect Mr. E. Vredenburg's recent work is extremely important in removing misconceptions caused by previous writers.[1]

The Post-Eocene beds may be treated as a whole; they are entirely continental in the extreme north, and except for the very highest beds, completely marine in the south. For the present the term "Pegu System may be taken to correspond essentially with the marine facies of the post-Eocene Tertiary. It ranges in age from lowest Oligocene to Pontian or the lower part of the Pliocene". The corresponding continental facies may be termed the Irrawadian. However, until recently the Pegu and Irrawadian were believed to

[1] The following are the more important works dealing with the Pegu-Irrawadian:—

Palæontological.—Noetling, "Fauna of the Miocene Beds of Burma": *Pal. Ind.*, N.S., vol. i, Mem. 3, 1901. Noetling's stratigraphical classification and his "zones" should be entirely ignored and no attempt should be made to use this memoir without reference to Vredenburg's "Results of a Revision of some portions of Dr. Noetling's Second Monograph of the Tertiary Fauna of Burma": *Rec. G.S.I.*, vol. li, pt. iii, 1920, pp. 224–302. Other fossils have been described by Dalton (some Eocene), *Q.J.G.S.*, vol. lxiv, 1908, pp. 604–44, but the stratigraphy of this paper is very unsound. Modern descriptions of certain groups of Pegu fossils by Vredenburg have appeared and are appearing in *Rec. G.S.I.*, vol. li, pt. iv (*Terebridæ*); vol. liii, pt. ii (*Pleurotomidæ*, *Conidæ*, etc.) (in progress).

Stratigraphical.—The foundation of stratigraphical knowledge in Lower Burma was well laid by Theobald, *Mem. G.S.I.*, vol. x, 1874. A useful summary of work done prior to 1911 is given by Pascoe, "The Oil Fields of Burma": *Mem. G.S.I.*, vol. xli, pt. i, 1912. Foundation for later detailed work is found in Cotter, "The Pegu-Eocene Succession in the Minbu District": *Rec. G.S.I.*, vol. xli, pt. i, 1912, partly revised by Cotter and Porro in *Rec. G.S.I.*, vol. xlv, pt. iv, 1915. The following papers are in need of revision as a result of later work: Stuart, *Rec. G.S.I.*, vol xli, pt. iv, 1912, pp. 240–65 (Henzada); Stuart, *Rec. G.S.I.*, vol. xxxviii, pt. iv, 1909–10, pp. 259–91 (Prome, etc.). Later work of importance includes Vredenburg, op. jam. cit., *Rec. G.S.I.*, vol. li, pt. iii, 1920, pp. 224–302, also pp. 321–37 (some rather serious errors occur in the correlation tables in the latter paper); Sethu Rama Rau and Vredenburg, *Rec. G.S.I.*, vol. liii, pt. iv, 1921–2, pp. 321–42 (Singu); also pp. 359–69 ("Correlation of lower beds of Pegu"), and Cotter, *Rec. G.S.I.*, vol. liv, pt. i, 1922 (in the press).

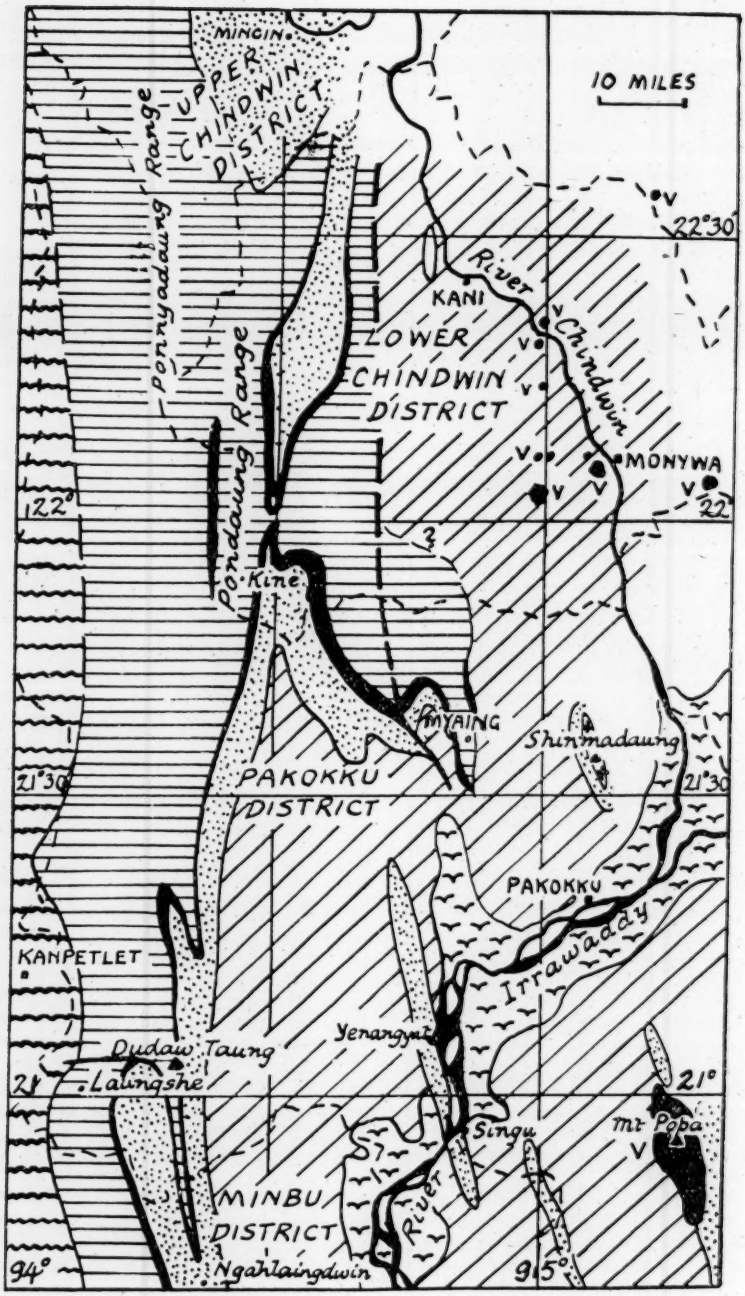


FIG. 4.—Geological sketch-map of part of the Tertiary Region of Burma, northern half. The upper half of this map is based entirely on personal field work, the remainder is reduced from the published maps of the Geological Survey of India.—L. D. S.

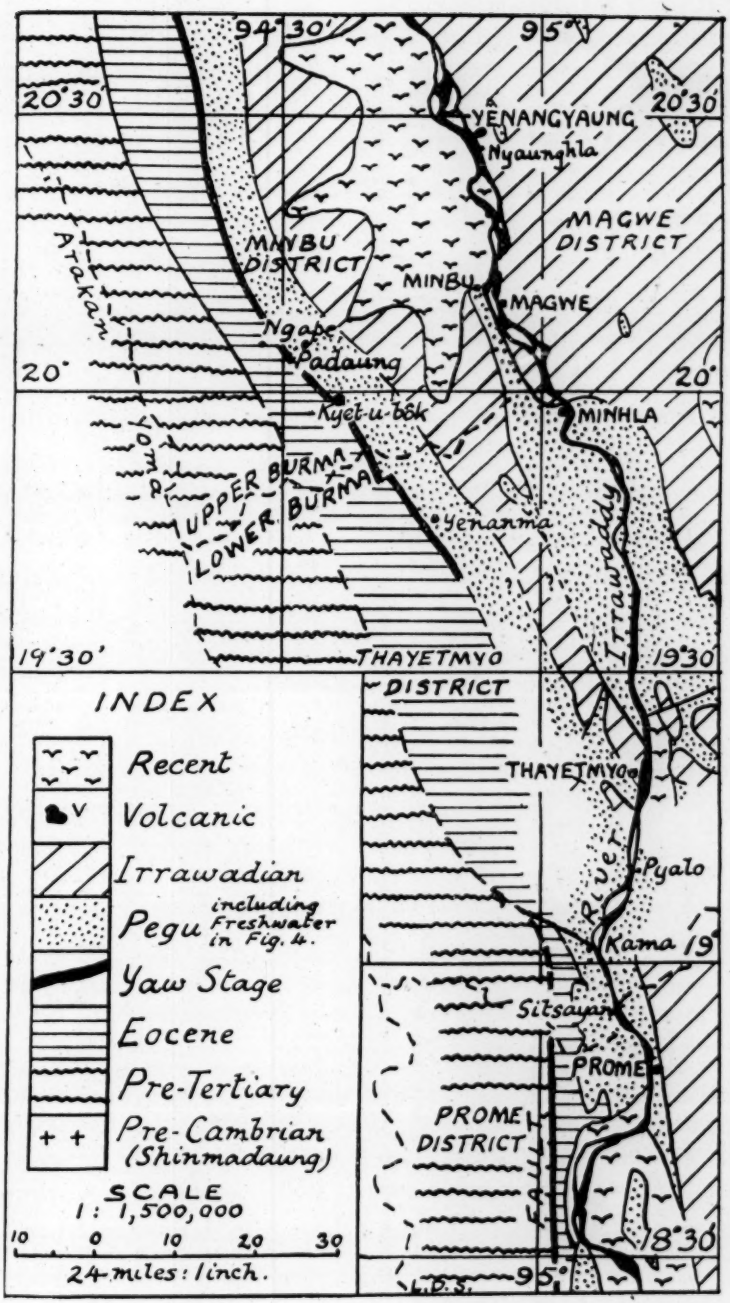


FIG. 5.—Geological sketch-map of part of the Tertiary Region of Burma, southern half. Compiled from various sources, supplemented by personal field work.—L. D. S.

be superimposed systems of different ages, and when it was found that the Pegu beds passed northwards into freshwater deposits, the latter were termed "Freshwater Pegus". For the present this term may conveniently be retained for those freshwater beds which are shown by their vertebrate remains to be earlier than the well-known Irrawadian of the Oilfield region of Yenangyaung, Minbu, etc.

1. *The Marine Post-Eocene or Pegu System (sensu lato).*

A number of horizons can now be distinguished on a palæontological basis ("Standard Faunas"), and at least some of the stages based on a study of these faunas can be traced through the changes of facies from Lower to Upper Burma. The relationship of the lithological divisions to the stages is far more easily expressed in diagrammatic form and a mass of detail has been incorporated in Fig. 3, which is not repeated in the text below.

Lithological Divisions (Lower Burma).	*Stages.*[1]	*Lithological Divisions (Upper Burma).*
Akauktaung Series.[2] Pyalo Sandstones.	Akauktaung and Pyalo Stages.	Represented by Freshwater beds (? base of Irrawadian).
Kama Clays.	Kama Stage.	Brackish upper part of Pegu.
Prome Beds ("A").	Singu Stage.	Exposed Pegu Beds of the Oil Fields of Minbu, etc.
Sitsayan shales with *Lepidocyclina* Limestones.	Sitsayan Stage.	Shwezetaw Sandstones, etc.
	Shwezetaw Stage.	
Kyet-u-bók Bed.	Kyet-u-bók Horizon.	*Velates* Bed (Dudaw Taung, etc.).

The total thickness of the Pegu System in Lower Burma may be taken to be roughly 10,000 feet.

Basal or Kyet-u-bók Bed.[3]

This bed, which the writer regards as the base of the Pegu System, is a well-marked calcareous band, conglomeratic in places with small quartz pebbles. It is characterized by four species of foraminifera, always present, but in very variable proportions. They are *Nummulites yawensis* Cotter (formerly described as *N.* cf. *beaumonti*[4] and *N. beaumonti*),[5] *Orthophragmina omphalus* Fritsch, *Operculina* cf. *canalifera* D'Arch., and *Gypsina globulus* Reuss. The associated mollusca include species common to the underlying Yaw Stage, notably *Velates orientalis*. Whilst the species of foraminifera mentioned occur in enormous numbers in the bed itself,

[1] Slightly modified from Vredenburg, *Rec. G.S.I.*, vol. liii, pt. iv, 1921–2, pl. xxv.

[2] "Marine Irrawadian" of Stuart, 1909–10; Mogaung Sands of Theobald, 1874.

[3] Named after a now non-existing village from whence it was first noted by Dalton, *Q.J.G.S.*, vol. lxiv, 1908, p. 612.

[4] Dalton, op. jam. cit., p. 612.

[5] Cotter, *Rec. G.S.I.*, vol. xli, pt. iv, 1911–12, p. 226.

they do not appear to range higher. It will be noticed that at least two of the foraminifera are Eocene forms. Taking a narrow palæontological view, one would be tempted to regard the Kyet-u-bôk Bed as Eocene. It is, however, distinctly a basal bed stratigraphically and its characteristics agree very closely with other typical basal beds. As a general rule, one may say that the fauna of a basal bed of a formation comprises :—

(*a*) Survivors from the preceding stage which occur in enormous numbers before their final extinction. Their number is frequently increased by the presence of numerous rolled specimens.

(*b*) Forerunners of the succeeding faunas. It is the presence of these new elements in the fauna which should really decide its age.

Amongst comparable examples may be noted the basal Ledian [1] with its but slightly rolled *Nummulites lævigatus* (the zone fossil of the preceding stage, the Lutetian) and the basal Ypresian, with its numerous Landenian species ;[2] both examples being from the Anglo-Franco-Belgian Basin. Amongst older rocks the basal bed of the Devonian of the Welsh Borderland may be noted.[3] The Kyet-u-bôk Bed has been traced by the writer for a distance of about 35 miles from near Ngapè to the south of Yenanma.[4] It appears to correspond exactly to a bed found at the top of the Yaw Stage from latitude 20° 15′ to 21° 15′, characterized by the presence of *Orthophragmina*, *Nummulites*, *Velates orientalis*, *Volutoconus birmanicus*, etc.

Shwezetaw Stage.

In Lower Burma the lowest Pegu Beds are shales—forming the lower part of the Sitsayan Shales of the Henzada and Prome districts. Passing northwards to the neighbourhood of Yenanma and Ngapè, one finds the Basal Bed is succeeded by a series of shales and then by a group of sandstones—the Shwezetaw Sandstones. The shales are usually unfossiliferous, but the writer found an interesting fauna, a few hundred feet above the base in Magyisan Chaung (latitude 19° 57′). The fossils have not yet been examined in detail, but they include forms closely allied to, but specifically distinct from, species described from higher horizons of the Pegu. Further north the sandstone facies invades the whole of the Shwezetaw Stage, and becomes of shallower-water type. About latitude 21° the sandstones resting on the fossiliferous Basal Bed contain coal seams, and the principal fossil is the brackish-water *Batissa* (*Cyrena*). The more marine type of Shwezetaw Sandstone (about latitude 20° 5′), seems to be characterized by *Ampullina birmanica* Vred., and this fossil is also found in the lowest Pegu (Shinmadaung Sandstones) where they rest on pre-Cambrian in the Shinmadaung area. Interbedded igneous rocks also occur in this district.[5]

[1] Stamp, Geol. Mag., Vol. LVIII, 1921, p. 198.
[2] Stamp, *Proc. Geol. Assoc.*, vol. xxxii, 1921, pp. 97–8.
[3] Stamp, *Abs. Proc. Geol. Soc.*, No. 1,075, 1921–2, p. 6.
[4] It is almost certainly continuous with Cotter's G_2 bed (op. cit., 1911–12, p. 226).
[5] Vredenburg, *Rec. G.S.I.*, vol. liii, pt. iv, 1921–2, pp. 359–69.

Padaung or Sitsayan Stage.

This stage seems to mark the period of greatest extension of marine conditions during Pegu times, being still definitely marine as far north as latitude 21° 6′ (Dudaw Taung) or even to 21° 40′ (West of Myaing). The stage is characterized by *Tritonidea martiniana*, and, towards the higher part, calcareous bands with *Lepidocyclina theobaldi*. In the south this division is represented by the *upper* part of the Sitsayan Shales with thick bands of *Lepidocyclina* Limestone. The latter were sometimes mistaken by Theobald (1874) for Nummulitic Limestones—as in Henzada and at "Lime Hill", near Thayetmyo.[1] Vredenburg believes that the lower part of the exposed Pegu in the oilfields of Minbu and Yenangyat belongs to this stage.[2]

Singu Stage.

Vredenburg has adduced evidence to show that the exposed Pegu rocks in the Oilfields of Yenangyaung and Singu and the higher beds in the fields of Minbu and Yenangyat are the equivalent of the Prome Beds (Division A of Theobald) of Lower Burma.[3] The latter are a sandy group about 1,500 feet thick. The faunas of all the Pegu stages discussed up to the present are of distinctly Oligocene character.

Kama Stage.

A predominantly shaley group found in Lower Burma which has recently yielded a magnificent series of fossils. The most fossiliferous beds occur about 700 to 1,000 feet above the top of the Prome Beds "A". The fauna is distinctly Miocene, and corresponds to the Gáj of Western India. This stage is probably represented by the highest Pegu Beds with brackish-water fossils (*Batissa*) in the oilfields of Upper Burma. The presence of the Miocene mammal *Docatherium* in the higher part of the Pegu of Yenangyaung supports this correlation. The "Freshwater Pegu" above the beds with *Tritonidea martiniana* in the Myaing region have yielded the lower Miocene mammal *Cadurcotherium*.[3]

Pyalo Stage.

A sandy group restricted to Lower Burma, which has yielded numerous examples of *Ostrea latimarginata*, a fossil characteristic of the Upper Gáj of India.

Akauktaung Stage.[4]

Formerly called "Marine Irrawadian" by Stuart, and corresponding to Theobald's Mogaung Sands. Yields *Ostrea virleti*,

[1] Cotter, *Rec. G.S.I.*, vol. liv, pt. i, 1922 (in the press).

[2] Vredenburg, *Rec. G.S.I.*, vol. li, pt. iii, 1921, pp. 224–302; *Rec. G.S.I.*, vol. liii, pt. iv, 1921–2, pp. 321–42.

[3] Pilgrim, *Rec. G.S.I.*, vol. xl, pt. iii, 1910, p. 197.

[4] The existance of an unconformity below this stage as claimed by Stuart is very doubtful.

O. digitata, and *O. gingensis*. It is doubtful whether this stage is really separable from the Pyalo Stage.

Summarizing, it may be said that, independently of their exact age, the higher beds of the Pegu (as at Minbu, Yenangyaung, and Yenangyat) are characterized by the presence of large *Cyrenæ*—*C.* (*Batissa*) *crawfurdi*, *C.* (*B.*) *noetlingi*, *C.* (*B.*) *petrolei*, etc.[1] These fossils occur also in the basal Irrawadian, probably derived. Throughout the Pegu there is a marked increase in shallow-water characters northwards.[2] The more homogeneous clays and shales of the south give place to the alternating shales and sandstones of the great oilfields. At Singu conglomeratic bands and "Bone Beds" are frequent, whilst further north remains of crocodiles and land vertebrates are found and lateritic "Red Beds" appear.

2. *The Continental Post-Eocene or Irrawadian System and "Freshwater Pegu".*

The "Freshwater Pegu" is naturally restricted to the more northerly parts of Upper Burma. North of latitude 21° 30′ the Eocene Yaw Stage passes up gradually into a mass of somewhat coarse sandstone. At the base, logs of wood bored by molluscs and afterwards silicified are frequent, whilst in the higher part, and especially further north, silicified wood is abundant. North of latitude 22° 45′ the Freshwater Pegu rests directly on the Pondaung Sandstone, and bands of quartz-pebble conglomerate and lateritic "Red Beds" become frequent. Vertebrate remains—especially crocodilian—are occasionally found, and the occurrence of *Cadurcotherium* in the higher beds near Myaing has already been mentioned (in the relative position marked "f" on Fig. 3).

The Irrawadian of Upper Burma comprises a thick series—certainly more than 5,000 feet in the neighbourhood of Yenangyaung—consisting mainly of coarse, current-bedded sands. At the base there is usually a well-marked "Red Bed" or old lateritic land surface. Associated with this band either above it or below, there is frequently a bed of white sand rich in kaolin. Interbedded bands or even beds of some thickness of a clay, which approaches pipe-clay in general characters, are frequent in the lower beds and again in the higher part of the Irrawadian. The Irrawadian is famous for the enormous quantity of silicified fossil wood which it contains—hence the old name "Fossil Wood Group" (Theobald). The series has also yielded a number of interesting vertebrate remains, notably near Yenangyaung. Specimens from this locality come from two distinct horizons :—

(*a*) Lowest beds containing *Hipparion punjabiense* Lyd. (*Hippotherium antilopinum* of Noetling and earlier writers), *Aceratherium lydekkeri* Pilg.

[1] Pascoe, *Rec. G.S.I.*, vol. xxxvii, pt. iii, 1908, pp. 143–6, but see Vredenburg, ibid., vol. li, pt. iii, 1921, pp. 262–6.

[2] Cotter, *Rec. G.S.I.*, vol. xxxvii, pt. iii, 1908, pp. 149–55 (Taungtha Hills); Cotter, ibid., vol. xxxviii, pt. iv, 1909–10, pp. 302–7 (Yenangyat).

(*A. perimense* of Noetling), crocodilian and chelonian remains. At this lower horizon *Mastodon* and *Hippopotamus* seem to be rare or absent, no undoubted occurrence being known to the writer.

(*b*) A conglomeratic band some 4,500 feet higher in the series and exposed along the banks of the Irrawaddy between Yenangyaung and Nyaunghla yielding numerous *Mastodon latidens*, *Stegodon clifti*, and *Hippopotamus irravaticus*.[1]

The lower horizon, that is the base of the Irrawadian at Yenangyaung, may be correlated with the Dhok Pathan horizon [2] (Upper Pontian), or, since *Mastodon* and *Hippopotamus* both seem to be absent, possibly with the Nagri horizon (Lower Pontian) of North-Western India.[3] In any case, *Aceratherium* indicates a pre-Pliocene age. The higher horizon agrees faunally with the Tantrot horizon (Lower Pliocene) of North-Western India. The presence of later Pliocene deposits amongst the Irrawadian is indicated by the presence of *Boselaphus* and *Bos* further north in latitude 22° 3′ (L. D. S.).

The Irrawadian probably extended much further south than it does at present. It may occur under the alluvial deposits of the Irrawadi delta; indeed, a fossil bed containing Irrawadian vertebrates mingled with fish remains (*Lamna*), and probably in situ, has been recorded from below the alluvium near Rangoon.[4]

V. Some Tectonic Considerations.

Whilst the buckling of the Tertiary geosyncline was going on throughout the Tertiary period, the main folding has affected even the highest Irrawadian, and is thus probably late Pliocene. It may be noted that, as with the folding in Burma, the end of the Cretaceous and the end of the Pliocene were two of the most

[1] Dr. G. E. Pilgrim, in his revision of the vertebrate fossils of the Irrawadian of Burma (*Rec. G.S.I.*, vol. xl, pt. iii, 1910, p. 196), has confused the specimens from these two horizons. He gives them in one list and says "It seems certain, however, that from the lowest beds [*sic*] of the Irrawadi series both Noetling and Grimes collected a distinctive vertebrate fauna which I have examined. . . ." If, however, one consults Noetling's account (*Mem. G.S.I.*, vol. xxvii, pt. ii, 1897, especially pp. 57, 58, and 59) one finds he says "specimens are particularly common along the river bank between Yenangyoung and Nyounghla. . . ."; again, "I am absolutely sure that certain species are restricted in the neighbourhood of Yenangyaung to the lower parts of the division. . . ."; then, after separating a lower "zone" of *Hippotherium antelopinum* and *Aceratherium perimense* from a higher "zone" of *Mastodon latidens* and *Hippopotamus irravaticus* he says that the two latter almost certainly do not occur lower. Grimes (*Mem. G.S.I.*, vol. xxviii, pt. i, 1900, pp. 30–79) separates the Irrawadian into four "zones"; from the lowest he only mentions *Cervus* sp., then after describing his highest "zone" as being exposed along the banks of the Irrawaddy says "It was from conglomerate beds of this zone that Mr. Crawfurd, Dr. Oldham, and in late years Dr. Noetling have obtained numerous fossil vertebrate bones. . . ." (p. 64). The writer's personal experience confirms these statements.

[2] Pilgrim, *Rec. G.S.I.*, vol. xliii, pt. iv, 1913, pp. 264–326.

[3] Or by direct comparison with France, an even earlier age is indicated.

[4] Pilgrim, *Rec. G.S.I.*, vol. xxxiii, pt. ii, 1906, pp. 157–8.

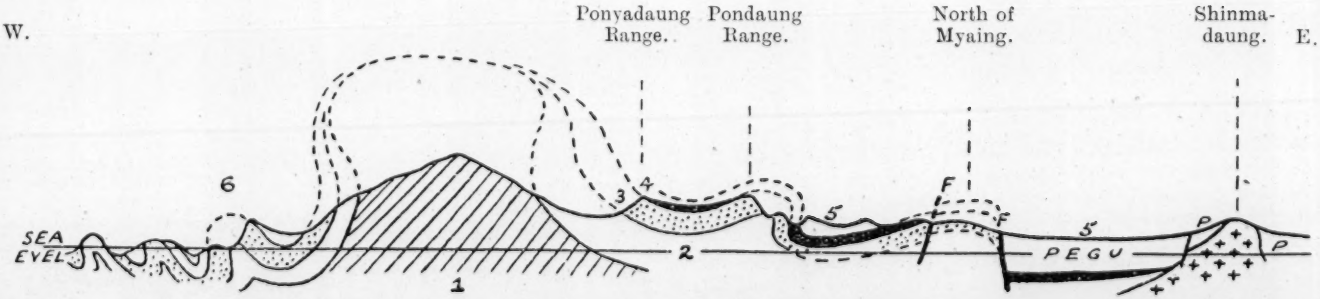


FIG. 6.—Diagrammatic section across the Arakan Yoma, approximately along latitude 21° 45′. Shows the anticlinorial structure of the range and illustrates the type of overfolding found on either side. The curious inlier of Pre-Cambrian schists—believed to be a pronounced case of the "buckling" of the Tertiary geosyncline—is shown on the right. 1. Pre-Tertiary. 2. Early Tertiary. 3. Pondaung Sandstone. 4. Yaw Stage. 5. Pegu-Irrawadian. 6. Deposits of Assam Gulf of Deposition.—L. D. S.

important periods in the folding of the Himalayas. The resulting structure of the anticlinorium of the Arakan Yoma and part of the Tertiary synclinorium are shown in Fig. 6. The manifestation of volcanic activity which has left its traces in the noble pile of Mount Popa and in the interesting Crater Lakes of the Chindwin was closely connected with the late Pliocene folding. It has been noted above that a ridge of pre-Cambrian rocks occurs in the centre of the Tertiary Belt at Shinmadaung. It may well be that this ridge extended much further southwards, and even separated an eastern from a western basin of deposition. This would explain the different characteristics exhibited by the Pegu rocks along the eastern side of the Tertiary Belt, but about which very little is yet known.

VI. Correlation with Europe.

Before attempting any general correlation with European deposits, it is absolutely essential to consider the geographical conditions of the period. Many of the Tertiary deposits of Europe were laid down in land-locked basins only in connexion with the main ocean (Tethys) at intervals. Thus, while the *sedimentation* in each basin may have been continuous and uninterrupted, there may be marked faunal breaks due to cessation of free communication with the ocean at certain periods. This is especially true of the Anglo-Franco-Belgian Basin where each stage is characterized by a particular species of *Nummulites*, but the intermediate species of *Nummulites*—completing the phylogenetic series—are only found in the main ocean. It is, however, absurd to suppose—as some writers have done [1]—that because a certain fauna (for example, that of the "Libyan" of Egypt) is not found in the Paris region, there exists a gap between the Ypresian and the Lutetian, which it should occupy. One may picture the geography of early Tertiary times as comprising a long ocean stretching from the south of France to India, and fringed, probably on either side, by partly enclosed gulfs or basins. In some parts of the main ocean we may expect to find a complete series of marine deposits, which should be used as a standard when comparing the development of the strata in any particular basin. Amongst the "fringing gulfs" may be mentioned those of the Punjab, of Assam, and of Burma. Still more separated from the ocean was the Anglo-Franco-Belgian Basin. Two further points must be borne in mind—firstly, the probable separation of the European and Asiatic portions of the Tethys in Miocene times, and secondly, that the Burmese Gulf was probably far more intimately connected with the Circum-Pacific Tertiary Basins than with the Tethys.[2] A rough correlation of the Burmese and North-Western European Tertiaries is appended in tabular form.

[1] *Rec. G.S.I.*, vol. li, pt. iii, 1921, pp. 325–6.

[2] Vaughan and others, "Correlations of the Post-Cretaceous Formations in the Pacific Region." Reprinted from special publication of Bernice P. Bishop Museum, No. 7, 1921, pp. 713–873.

VII. Conclusion.

In conclusion the writer wishes to express his thanks to Messrs. The Yomah Oil Company (1920), Limited, for permission to publish the original observations incorporated in this paper. To the officers of the Geological Survey of India the most cordial thanks are accorded. When assistance has been given so whole-heartedly, it is almost invidious to mention individuals, but in particular the writer has profited by discussion with Dr. G. de P. Cotter and Mr. E. L. G. Clegg, and by the help of Dr. J. Coggin Brown in the Survey's offices at Calcutta.

	Burmese Gulf.	*N.W. Europe.*	*N.W. India.*
Pliocene.	Higher Irrawadian.	Pliocene (*sensu stricto*).	Gwadar.
Miocene.	Akauktaung Stage and basal Irrawadian.	Helvetio-Pontian.	Talar.
	Pyalo Stage.	Burdigalian.	Upper Gáj.
	Kama Stage.	Aquitanian.	Lower Gáj.
Oligocene.	Singu Stage.	Chattian.	Upper Nari.
	Sitsayan Stage.	Stampian.	Lower Nari.
	Shwezetaw Stage.	Sannoisian.	
	Basal Bed.		
Eocene.	Yaw Stage.	Bartonian. Ledian.	
	Pondaung Sandstone.	Lutetian.	Kirthar.
	Tabyin Clays.		Laki.
	Tilin Sandstone.	Ypresian.	
	Laungshe Shales and Paung-gyi Conglomerate.	Landenian.	Ranikot.

The Barrettia Beds of Jamaica.

By C. T. Trechmann, D.Sc., F.G.S.

(PLATES XVIII–XX).

Introduction.

Barrettia, the most abnormal of the Rudistæ, and among the strangest of all the mollusca, was first found in Jamaica by Lucas Barrett, F.G.S., in the year 1861. The specimens were ably described by S. P. Woodward, F.G.S., in 1862.[1] The original

[1] "Some account of *Barrettia*, a new and remarkable shell from the Hippurite Limestone of Jamaica": *The Geologist*, London, 1862, pp. 372–7.

specimens, now in the British Museum of Natural History, consist of polished transverse and longitudinal sections of the upper part of the shell, the latter showing the junction of the upper and lower valves, and a cross section of the young shell near the apex of the lower valve. They were called *Barrettia monilifera* in honour of the discoverer. The locality where they were found was on the banks of the Back River, a tributary of the Rio Grande, about 15 miles from the coast in Portland Parish in the north-east of the island. The rock is described as a hard, grey limestone which occurs in bands of a few inches to a yard in thickness, subordinate to many hundreds of feet of shale which graduate up into other grey shales of the Eocene, followed by white limestones of Miocene age.

The original specimens, therefore, come from the far easterly part of Jamaica, namely the Blue Mountain district, where the limestones are as a rule hard and splintery, and the fossils indifferently preserved and difficult to disengage from the rock. The stratigraphy in this portion of the island is also much involved, though Barrett's description is clear enough. I did not succeed in finding the locality, which is in a wild and inaccessible area.

J. G. Sawkins[1] records a derived specimen of *Barrettia* as occurring, together with other rolled fragments of Cretaceous limestone and other Cretaceous fossils, in the conglomerates and sandstones of the Carbonaceous or Black Shale series, later called by Hill the Richmond Formation, near Port Maria. These beds comprise an accumulation of material derived from the Cretaceous and older land, and the conglomerates at Port Maria contain also fresh and slightly rolled Eocene mollusca. The only specimen of *Barrettia* I saw in the collection of the Jamaica Institute in Kingston is an apparently rolled example, and may be the identical example found by Sawkins in the Carbonaceous Shale.

I have not been able to trace definite records of its occurrence in Cuba, but Matthew[2] states that limestones at Constancia Landing and Conception Estate are of pale buff tint, and are Hippurite limestones, and contain several species of *Caprinella* and *Caprotina*.

T. W. Vaughan[3] states that it has been collected in the province of Santa Clara in Cuba. A similar fauna which may contain *Barrettia* is also reported from Haiti.

Its occurrence in Guatemala seems to be more definite. C. Sapper[4] says that the greater part of northern Guatemala is made of thick limestones, which often alternate with dolomite and limestone breccias, and that these are for the most part certainly Cretaceous. He goes on to say that the remarkable genus *Barrettia*, which

[1] "Reports on the Geology of Jamaica": *Memoirs of the Geological Survey*, London, 1869, p. 130.

[2] *Canadian Naturalist*, vol. vii, 1872, p. 19.

[3] Bailey Willis, "Index to the Stratigraphy of N. America": *U.S. Geological Survey*, Professional Paper 71, 1912, p. 643.

[4] Sapper, "Grundzuge der Physikalischen Geographie von Guatemala": *Petermanns Mitteilungen*, Ergänzungsheft 113, 1894, p. 9.

hitherto is recorded only from Jamaica, is found near Samac and Campur, and that in the north-west of the Department of Huehuetenango Rudists, mostly *Sphærulites*, were found.

There can be no doubt that further research will extend the range of this and numerous other Rudists in Central America and the Greater Antilles.

Several specimens were collected in Jamaica in 1895 and 1896 by Mr. F. C. Nicholas, of New York. Most of these came from Orange Cove, Hanover Parish, in the far west, but two of them are recorded from Logie Green, in Clarendon Parish, near the centre of the island.

The specimens were sent to New York and described by R. P. Whitfield [1] under the names of *Barrettia monilifera*, *B. multilirata*, and *B. sparcilirata*, the last two being new species. No description of the locality nor indication of the horizon of the beds occurs in Whitfield's paper, and none of the specimens was well enough preserved to allow of the upper valve being seen. Moreover, Whitfield throws grave doubts on the molluscan nature of these fossils, and feels much more inclined to consider them as pertaining to the Cœlenterates rather than to any form of the mollusca. He cites several features in his specimens which he regards as entirely incompatible with the growth of a molluscan body, but allied to that of the cup corals.

R. T. Hill, in his work on the geology of Jamaica,[2] does not mention having seen *Barrettia* during his sojourn in the island at any of the three localities from which it is reported. The locality at Haughton Hall, near Green Island, where it occurs is coloured on his map apparently as "Cambridge" formation, which he regards as Eocene, though containing Cretaceous and Tertiary fossils. The exact spot on his map is difficult to locate, but it is apparently very near his junction of Richmond, Cambridge, and Cobre, Moneague, and Montpelier formations.

H. Douvillé [3] has submitted the original specimens collected by Barrett to a critical re-examination, and has no doubt that the genus is a Rudist mollusc, an opinion which I fully share.

Barrettia is an important fossil for the following reasons:—

(*a*) It is one of the few representatives of the great group of the Hippuritids on the American side of the Atlantic Ocean. The genus *Hippurites* does occur there, however, and Professor Douvillé kindly showed me a small form of it from Mexico, preserved in the museum of the School of Mines in Paris.

[1] "Observations on the Genus *Barrettia* of Woodward, with descriptions of two new species": *Bulletin American Museum of Nat. History*, New York, vol. ix, 1897, pp. 233–46, pls. xxvii–xxxviii.

[2] "The Geology and Physical Geography of Jamaica": *Bull. Mus. Comp. Zoology*, Harvard, vol. xxxiv, 1899.

[3] "Études sur les Rudistes": *Mem. Soc. Geol. de France*, tome iv, fasc. ii, 1894, p. 110, pl. xvii.

(*b*) Its relation to the Rudist mollusca has been denied by Whitfield, though the intermediate stages between *Barrettia* and *Hippurites* are sufficiently apparent in the genera *Batolites*, of Montfort, and *Pironæa*, of Meneghini. Douvillé has pointed out that the young of *Barrettia monilifera* passes through a *Pironæa*-like stage.[1] *Pironæa* occurs derived in Eocene conglomerates in North Italy and also in Spain and Asiatic Turkey.

(*c*) Owing to Hill's reported occurrence of the commingling of Cretaceous and Tertiary fossils in beds which he calls the Cambridge and Catadupa formations in Jamaica, the actual Cretaceous age of *Barrettia* and other Rudists was thrown into doubt.

For these reasons I was particularly desirous during a recent stay in Jamaica to acquire some information on these points, and consequently to find the locality near Green Island where *Barrettia* was reported to occur in quantity and presumably in good preservation. In this search I was greatly assisted by two friends of the Public Works Department of Jamaica, Mr. P. Martin Cooper, A.M.I.C.E., and Mr. F. D. Jenoure, who kindly made exhaustive inquiries for me. Mr. Jenoure found a negro who happened to have watched Nicholas when he was collecting twenty-seven years ago, and consequently was able to take me near the spot, as a result of which I was soon able to trace the outcrop of the Barrettia limestone. This was some days after Dr. Matley and I had spent several hours of a very hot afternoon in a fruitless search for the *Barrettiæ*.

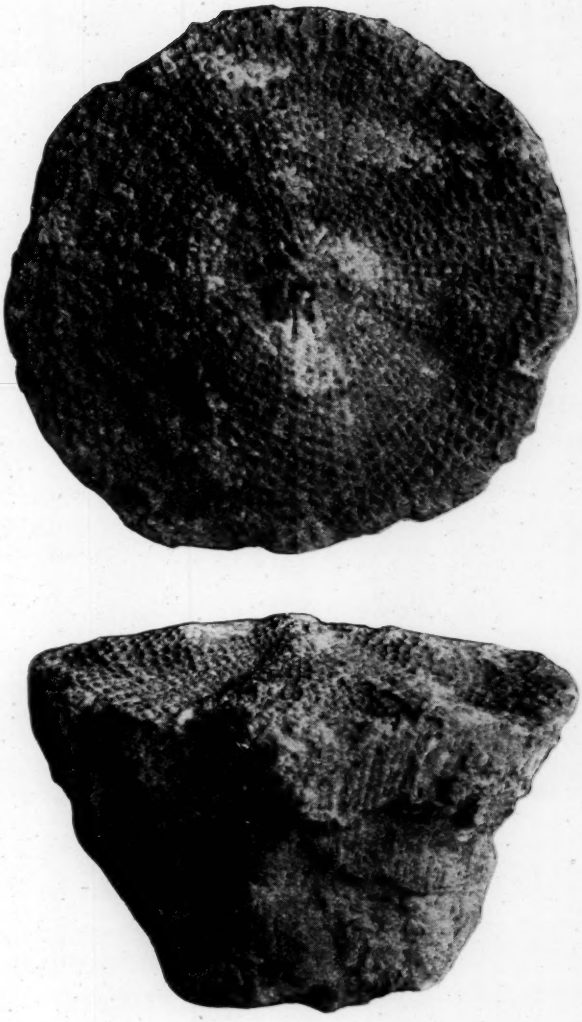
My activities were devoted to securing a series of *Barrettia* in various stages of growth and states of preservation, and also of the large crateriform Radiolite *R. nicholasi* Whitfield, which was reported to be the only other fossil accompanying the *Barrettia* in this locality, and is, in fact, the only other large and conspicuous fossil. The search for other smaller accompanying fossils, however, was not unsuccessful, though these, except in the case of certain foraminifera, are very scarce.

It also seemed desirable, as far as possible, to determine the relation of the Barrettia limestone to the other limestones, conglomerates, shales, etc., that occur above and below it, as well as its relation to the Tertiary beds, and to see if any trace of *Barrettia* was to be found in other localities in Jamaica.

Hitherto, except for two incomplete specimens of a species which Whitfield calls *Barrettia sparcilirata*, recorded from Logie Green on the Rio Minho, the only localities for this genus are that on the Back River in Portland Parish in the extreme east, and near Green Island, in Hanover Parish, in the extreme west of the island.

I saw no trace of *Barrettia* in any of the other Rudist limestones in Jamaica, such as that at Jerusalem Mountain in the far west; Logie Green and the Minho Valley; the Great River Valley, including the Cambridge and Catadupa railway sections; nor in the semi-

[1] "Études sur les Rudistes," p. 111.



1a

1b

C. T. T. photo.

BARRETTIA CF. MULTILIRATA WHITF.: VAR. CONICA NOV.
Jamaica. Half natural size.

To face p. 504.]

metamorphosed Cretaceous limestone outcrops near Moore Town and up the Plantain Garden River in the far east of the island. This, however, by no means precludes the possibility of their occurrence at one or other of these localities.

A large and extremely interesting series of Cretaceous fossils is obtainable at all of the above-mentioned localities, both in the limestones and in shales and mudstones which underlie certain of the limestones and are mapped by Sawkins as part of his Trappean Series. The study and investigation of these faunas will require a very considerable amount of time and trouble, and as this paper is intended to deal only with the Barrettia beds, their description must be reserved till some future occasion.

Since none of the other typical Cretaceous limestones is to be seen above or below it at Green Island, it is impossible to ascertain by direct observation in this locality where in the sequence the Barrettia limestone should occur.

The Rudist limestones of Jamaica appear to consist of discontinuous lenticular reef-like intercalations among the great thickness of fragmental sediments known as the Blue Mountain Series. The general association of fossils seems to me to be rather different in each of the typical Cretaceous limestone sections already referred to, some fossils occurring in one locality and not in another. This makes the attempt at any system of correlation or zonal sequence applicable to the Cretaceous of the island as a whole seem a rather fruitless task. Nevertheless, I feel convinced that in certain sections, such as that at Jerusalem Mountain and that about Logie Green, a faunal sequence of the Rudists and other mollusca can be traced. In this connexion I may mention that the large Radiolites (*Lapeirousia*) *nicholasi* Whitfield that accompanies *Barrettia* at Green Island is common in the lowest Rudist limestones that are exposed in the bed of the Rio Minho below Logie Green, where it occurs beneath a fairly thick bed of "Trappean" conglomerate. It occurs also in a road-cutting for some distance above the conglomerate bed, but I saw no trace of it in the higher Rudist beds exposed at Logie Green, and its position is at least two hundred feet below the top of the Cretaceous beds exposed there.

This fact goes to indicate the somewhat low horizon of the Barrettia bed in the Jamaican Cretaceous limestone sequence. I am inclined to suspect, however, that all the Cretaceous limestones in Jamaica are of very late date, probably Maestrichtian.

Description of the Beds.

The Barrettia limestone from which my collections were made occurs on the Haughton Hall estate, near Green Island Harbour, in Hanover Parish in Western Jamaica. The locality is apparently the same as that referred to by Whitfield as Orange Cove. The name Orange Bay is given on some maps to part of the coast which lies some two miles south-west of the ridge of Barrettia limestone at Haughton Hall.

The outcrop is included in the most westerly of the several inliers of older rocks that protrude from below the Tertiary White Limestone covering of the island. No Cretaceous limestone is mapped by Sawkins in this locality, the spot where the outcrop occurs being indicated as Trappean, bounded on the north and west by White and Yellow Limestones. No mention of *Barrettia* occurs in the text of Sawkins, and so the limestone outcrop seems to have been overlooked. The Barrettia limestone occupies approximately the northern and north-eastern portion of the outcrop, which Sawkins maps as Trappean, and the Tertiary White Limestone of presumed Oligocene age is clearly faulted down against it along some distance on the north, as I have indicated in a diagrammatic section (Fig. 1).

It consists of a grey nodular rather massive limestone, which shows stratification and bedding fairly well in places. The first outcrop one encounters on approaching from the sea on the north forms a picturesque wooded and flower-covered ridge, about 200 feet above sea-level. The Barrettia limestone forms an escarpment facing south and strikes about E.N.E. and W.S.W., and is rather lower than the

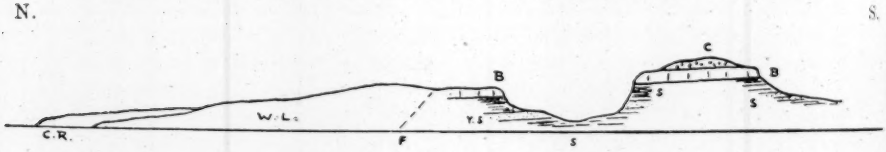


FIG. 1.—Diagrammatic sketch showing position of the Barrettia Limestone near Green Island, Western Jamaica. Length of section about a mile. Height about 300 feet above sea-level. F. fault; C.R. coral rock; W.L. White Limestone (Tertiary); B. Barrettia Limestone; C. "Trappean" conglomerate; S. grey and red calcareous shales; Y.S. yellow sandstone. The shales and sandstones appeared to be unfossiliferous.

ridge of White Limestone on the north. It dips about 20 degrees to the north and north-east, and has a thickness of 16 or 20 feet. On the opposite side of a small valley to the south, down which a stream runs, the Barrettia limestone crops out again round the edges of a rather higher hill, and forms an escarpment and a small cliff facing north and west. The surface of the limestone here weathers to clay, and is occupied by yam-fields, and the enclosures and stone heaps are largely made up of *Barrettia*, some of them excellently preserved. Further to the south the limestone seems to be cut off by faults, as the hill opposite the escarpment consists of red Trappean beds.

Some negro labourers were kindly provided by Mr. Jenoure, and so I had a cutting made down the wooded slope of the valley to ascertain definitely what rock underlay the Barrettia limestone, and found it to consist of a grey, friable nodular limestone overlying a sandstone. In the bed of the stream grey calcareous shales, locally called "Bruggadoo", are exposed. This is a negro term given to the rich soil formed from the weathering of shales and marly limestones specially suitable for banana growing.

On the slopes and summit of the hill above the yam-fields just mentioned the ground is strewn with pebbles, which indicate that the Barrettia limestone is overlain by Trappean conglomerate, though I did not find any actual outcrop of it. This conglomerate must form a capping of 30 or 40 feet on the hill-top, and there are indications of one or two bands of unfossiliferous or sparsely fossiliferous light-coloured limestone in it.

The pebbles in the Trappean conglomerate consist of—

Gneiss with pink felspar and dark mica.
Pink quartzite.
Indurated jaspery much contorted clay slates.
Lava of andesite aspect.
Dioritic rock.

The series is very similar to that which one encounters in several conglomerate beds in the Blue Mountain Series in Jamaica.

The section of the beds at Haughton Hall, therefore, appears as follows :—

	Feet.
" Trappean " conglomerate (including limestone bands)	30–40
Barrettia limestone	16–20
White and grey friable nodular marly limestone . .	60
Yellowish grey sandstone	
Grey sphæroidally weathering calcareous shale . .	

Barrettia is very plentiful in the limestone, and rolled down the slopes below it, and it often occurs in clusters of twos or threes joined together for some distance above the apices. In places in the rock they occur lying on their sides and crushed. *Barrettia* is a large and solid though comparatively stumpy Rudist, and I did not trace any for a greater length than about 3 feet. The greatest diameter of the large specimens is about a foot. The large crateriform Radiolite *R. nicholasi* Whitfield also occurs, but is much less plentiful than *Barrettia*.

To the westwards the bed of Barrettia limestone seems to have a lenticular shape and to thin out towards the hill slope. Both *Barrettia* and the large Radiolites seem to be restricted in areal distribution, and the bed in places passes into a hard grey limestone, rather like other Cretaceous limestones of the island. Here and there it shows sections of small Radiolites and other fossils, which, however, are almost impossible to recognize specifically owing to the hardness of the rock. There is a noticeable absence at Haughton Hall of several of the species of corals and other fossils that occur plentifully in other Cretaceous sections in the island.

The association of fossils and the fact that the Barrettia limestone is overlain by a " Trappean " conglomerate very similar to those commonly associated with the Blue Mountain rocks, and is underlain by a calcareous shale, proves that it belongs to the Cretaceous series, and is not in any way associated with the Tertiary formations of the island.

Palæontology of the Barrettia Bed.

The following is the list of fossils found up to the present in this bed :—

Barrettia cf. *monilifera* Woodward.
,, cf. *multilirata* Whitfield.
,, ,, var. *cylindrica* nov.
,, ,, var. *conica* nov.
Radiolites (*Lapeirousia*) *nicholasi* Whitfield.
Caprina jamaicensis Whitfield. Upper valve of a small specimen, 25 mm. wide.
Caprinella (?) sp. Curved upper valve badly preserved.
Radiolites sp. Sections in the hard limestone.
Ostrea sp. Small species adhering to the Barrettias.
Chama sp. A right valve rather like *Ch. haueri* Zittel of the Gosau beds.
Lima sp.
Cardita (*Venericardia*) cf. *subcomplanata* d'Archiac.
Avellana (*Eriptycha* ?) cf. *decurtata* Zekeli.
Echinoid, probably a new genus allied to *Lanieria*.
Foraminifer. A lenticular form in shape like *Orbitoides*, measuring up to 6 mm. in diameter. Professor Douvillé assures me that the internal structure is not that of *Orbitoides*.[1]
Sponge ? A large irregularly cylindrical object about a foot long, possibly a calcareous sponge, but the structure obscured by recrystallization.

Notes on the Fossils.

The intention of this paper is rather to record the conditions of occurrence of *Barrettia* in Jamaica than to enter into questions of the morphology or evolution of the organism, a matter which would require much slicing and polishing of specimens for which I have no time at present. There are one or two features, however, to which I should like to draw attention. One of these is the upper valve or lid, which has hitherto never been seen in a satisfactory state of preservation. Barrett's original specimen in the British Museum has the lid in place, but the decoration of its surface is all but obliterated. Among the yam-fields at Haughton Hall several examples of *Barrettia* occurred, showing the surface of the upper valve in more or less perfect preservation. I am illustrating some of these, hoping they will prove of use in fixing further the affinities of this peculiar fossil.

The top valve of *Barrettia* is, in comparison with the size and massiveness of the lower valve, a remarkably thin and fragile structure, and instead of being definitely flat, concave, or convex, as in the case of most Hippurites, it is in many specimens curiously

[1] I await with interest Professor Douvillé's report on this and other Jamaican foraminifera.

undulating in form, following the irregular surface of the lower valve. It is generally only in young individuals, especially of the species *B. monilifera*, that the decoration of the surface of the top valve can be seen. In older specimens the decoration both of the lid and of the sides of the lower valve is generally obliterated by erosion or overgrown by oysters and other adherent organisms. The top valve, in fact, is so thin that in the majority of specimens it has been partly or completely crushed into the visceral cavity during the process of fossilization.

The question arises in one's mind why did *Barrettia* develop the exaggerated system of infoldings of the outer layers of the shell, the moniliform rays or pallial duplicatures, as they have been termed, which forms the most conspicuous feature of the genus, and which in polished cross-section resemble a string of beads. The answer seems to be that the animal was one of a relatively small size; the diameter of the living chamber in my specimens is generally about one-third the diameter of the top part of the lower valve. In fact, several of these large shelly structures seem to have been built up by an animal not much larger than a good-sized modern oyster. The hinge teeth of the upper valve are consequently comparatively small and weak, and the lid would require some additional method of fixation to the lower valve when closed. This was accomplished by numerous projections from the lower surface of the lid fitting into cavities on the surface of the lower valve round the edges of the living chamber. These cavities or depressions occupy the spaces between the radial infoldings and a system of vertical shelly walls arranged concentrically and more or less parallel with the outer wall. A large number of projections serving the purpose of hinge teeth are therefore developed on the under surface of the lid, and fit closely into the cavities below, whose walls are formed by the rays, as I have already described.

The reason which impelled *Barrettia* to build up such an enormously greater amount of shell in comparison with the size of the animal than does *Hippurites*, is not so easy to see, but presumably it had to withstand greater battering from waves, or to adopt protection against some special enemy.

Whitfield describes the moniliform rays, or lines of beads as they were called by Woodward, as vertically septate tubes.[1] He also describes the first pillar as a longitudinal septate tube extending the entire length of the body. The second pillar he describes as a fosset-like body, and compares it with the fosset of a palæozoic cup-coral. In fact, he can find no evidence of a molluscan nature except the presence of the upper valve in Barrett's original specimen. He also attempts to describe the visceral cavity, but a glance at his specimen figured on pl. xxxv shows an example with the living chamber badly weathered. If one obtains specimens which allow

[1] "Observations on the genus *Barrettia*," loc. cit., p. 239.

the living chamber to be cleaned out and developed, it is seen to agree very well in detail with the living chamber of the genus *Hippurites* (see Pl. XX, Fig. 1). Though contending all through his paper for the similarity of *Barrettia* to the palæozoic corals rather than to the mollusca, Whitfield, nevertheless, is content to retain the generic name *Barrettia*, which was distinctly defined by Woodward as belonging to a molluscan structure.

Whitfield recognizes three species among the Jamaican material which was sent to New York by Mr. F. C. Nicholas ; these are—

Barrettia monilifera Woodward.
,, *multilirata* Whitfield.
,, *sparcilirata* Whitfield.

The two first species were collected at Orange Cove or Haughton Hall, near Green Island, the last only at Logie Green, in Clarendon Parish, near the centre of Jamaica.

Barrettia cf. *monilifera* S. P. Woodward. Pl. XIX, Figs. 2*a*, *b*. Pl. XX, Figs. 1, 2.

1862. "Some Account of *Barrettia*" : *The Geologist*, p. 372.

Description.—Several examples in my collection are apparently referable to the type species as regards the number of the septa and other features. The top valve is remarkably thin, and follows the uneven contour of the surface of the lower or attached valve, which is frequently curiously irregular and undulating. In large individuals the surface of the upper valve is much eroded and battered or overgrown with oysters or other shells, and the ornamentation thereby obscured, but in younger specimens the decoration is often preserved. It consists of a series of irregular saucer-like depressions which are frequently elongated in a direction parallel to the margin of the shell, and form a very irregular reticulate ornamentation (see Pl. XIX, Fig. 2*a*). The depressions correspond on the under side of the top valve with peg-like projections, which fit into pits on the surface of the lower valve. These pits are remarkably irregular in size and distribution, some being 10 mm. deep, others quite shallow (Pl. XX, Fig. 1). In young examples of this species the decoration of the sides of the lower valve is well shown, and consists of fairly regular, sharply incised, but shallow sulci, which radiate from the apex of attachment and pass up to the margin of the valve. Other similar sulci are interposed between these some distance above the apex, the sulci corresponding with the moniliform rays (Pl. XIX, Fig. 2*b*). In young specimens there is an embayment of the margin of the lower valve corresponding apparently with the original position of the hinge-line, but this feature is lost in older examples where the valve attains a circular outline. I could not detect any trace of external grooves on the lower valve to correspond with the position of the pillars, as is the case with most species of *Hippurites*.

The spacing of the moniliform rays is very irregular and in places they are much more crowded together than in others, and the shell

in aged specimens seems to have been frequently broken, presumably by battering of the waves, and very irregularly repaired by the animal. This species seems to have generally grown singly and alone, as I have only seen few with any trace of attachment of others to their sides.

Dimensions.—The largest example I saw measured about 2½ feet in length and 1 foot in diameter at the top. In such aged examples as this the ornamentation of sides and top is nearly worn away, and the shell much eroded. The smallest is quite an infantine specimen, 2 inches high, the top valve irregularly convex and oval in outline, measuring 4 inches in longer and 3 inches in smaller diameter, the living chamber rather over 1 inch in longer diameter.

Woodward's original specimen has sixty-five moniliform rays, but the number increases with age, and a specimen of mine a foot in diameter has about ninety. Another small specimen has sixty-nine or seventy rays.

Locality.—Barrettia bed, Green Island, Jamaica. The type specimen came from Back River, Portland Parish, East Jamaica. Maestrichtian (?). Several examples were collected at Green Island in various stages of growth.

Barrettia cf. *multilirata* Whitfield. Pl. XVIII, Figs. 1*a*, *b*; Pl. XIX, Fig. 1; and Pl. XX, Fig. 3.

1897. *Bull. American Mus. Nat. History*, vol. ix, p. 244, pls. xxxiii–xxxv.

Since the top valve of this and other Barrettias was unknown to Whitfield, it follows that his diagnosis of the species is incomplete. Those in my collection which are identifiable with the above species as regards their smaller size and the fact that in proportion to their size they bear a much greater number of moniliform rays, fall into three or more fairly distinct varieties as regards shape characters. The species is a much smaller one than is *B. monilifera*, being more slender and never attaining the clumsy irregularity of growth that *B. monilifera* does. The varieties may be described as follows:—

(*a*) Large examples with a long, often bent, very gradually tapering lower valve and a rather convex upper valve. Height 12–14 inches, diameter at top 7 inches. Typical form (?). See Plate XIX, Fig. 1. Several examples were collected.

(*b*) Slender, tapering rather gradually to the apex, the top valve nearly or quite flat. Height of lower valve 11 inches, diameter at top 5 inches. Several individuals seem to have grown together; the sides are often flattened, indicating where another individual grew against it. Var. *cyclindrica* nov. See Plate XX, Fig. 3. Two specimens, one figured and another sent to Professor Douvillé in Paris.

(*c*) Stumpy, conical, or almost mushroom-shaped, the top valve convex and irregular, with a central raised apex. Height 4 inches, diameter of top valve 6¼ inches. This form seems to have grown singly and alone. Var. *conica*, nov. See Plate I, Figs. 1*a*, *b*. Two specimens collected, one figured.

The decoration of the sides of the lower valve and surface of the lid is alike in all these shape variants. That of the sides consists of longitudinal incised sulci, between which are raised ridges, which are often striated longitudinally by smaller parallel sulci, and cut transversely by small growth interruptions. The decoration of the top valve is of a much more complicated nature than that of *B. monilifera*, and consists of irregular rounded ribs radiating from a central apex, often breaking up into two or three divergent ribs, and between them cross ribs arranged parallel with the margin of the valve. Between these, again, more smaller ribs diverge, forming a reticulate or honeycomb-like design. The lid in this species is stronger and thicker and less irregular in surface than it is in *B. monilifera*, and the two apertures or foramina of the lid, corresponding to the position of the first and second pillars in the living chamber, are more or less well shown (Pl. XIX, Fig. 1). The depressions or pits of the surface of the lower valve round the living chamber are very regular, numerous, and sharply defined, and consist of rectangular cavities generally elongate in a direction parallel to the margin of the shell. The shelly walls bounding these cavities parallel to the margin are sharp-edged, and pass generally from one node to another of the moniliform rays.

Locality.— Barrettia bed, Green Island, Jamaica. Maestrichtian (?).

Barrettia sparcilirata Whitfield.

1897. *Bull. American Mus. Nat. History*, vol. ix, p. 245, pls. xxxvi, xxxvii.

This species, which is recorded only from Logie Green, is described as having twenty-three rays and a diameter of 5 or 6 inches, and to be of a cylindrical or turbinate shape. Whitfield records that a portion of the external surface of the lower valve is visible on this species, the only example among his collection which exhibited this feature.

The fewness of its rays rather seems to suggest some connexion with the genus *Pironæa*, but in that genus the radial infoldings are not cut up into " strings of beads " as they are in *Barrettia*.

Cardita (*Venericardia*) cf. *subcomplanata* d'Archiac. Pl. XX, Fig. 4.

1853. *Description des Anim. fossiles du groupe nummulitique de l'Inde*, p. 253, pl. xxi, figs. 10, 11.

1897. Noetling, " Fauna of the Upper Cretaceous (Maestrichtian) Beds of the Mari Hills " : *Pal. Ind.*, ser. xvi, vol. i, pt. iii, p. 46, pl. xii, fig. 3.

The right valve of a rather flattened and compressed *Cardita* seems to be approximately identifiable with the above Indian species. Its outline is nearly semicircular, but compared with the figure of d'Archiac, the Jamaica shell seems rather more rounded, the beaks rather more pointed and more anteriorly situated, and the ribs rather broader than the interspaces between them, and the lunule slightly more excavated. There are eighteen or twenty gently curved radiating ribs.

Dimensions.—Length and height 20 mm.

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1

2a

2b

C. T. T. photo.

BARRETTIA CF. MULTILIRATA WHITE. (rather under $\frac{1}{2}$ nat. size); B. CF. MONILIFERA WOODW. (rather over $\frac{1}{3}$ nat. size).

Locality.—Barrettia bed, Green Island, Jamaica. One specimen. Noetling records his species from the Dés Valley, in Baluchistan, and he thinks that d'Archiac's specimen from Sind is also from Upper Cretaceous beds.

Avellana (*Eriptycha* ?) cf. *decurtata* Zekeli. Pl. XX, Fig. 5.

1852. "Gastropoden der Gosaugebilde": *Abhandl. der Kais. Koen. Geol. Reichsanstalt.*, Bd. i, Abt. ii, No. 2, p. 45, pl. viii, figs. 1, 3.

An Avellanoid gastropod occurs on the same piece of rock as the *Cardita* just described. The aperture is embedded in the matrix, so one cannot be sure to which of the Cinulid genera it should be referred. The spire is low and rounded, though it seems to project rather more than is the case with the Gosau form, and the Jamaica shell is altogether larger. The Gosau species is ornamented on the last whorl with twenty to twenty-five fine spiral lines, while the Jamaica form has only about twenty.

Dimensions.—Length 12 mm., diameter of body whorl 12 mm.

Locality.—Barrettia bed, Green Island. One specimen.

Lima (*Limatula* ?) sp.

A small *Lima*, having the general elongate outline of *L. gibbosa* Sow., occurs also on the same rock fragment as the two foregoing fossils. It is a left valve, 20 mm. high and 17 mm. wide, with about eighteen smooth rounded ribs radiating from the beak.

Echinoidea.

I collected at least four genera of echinoids both in and just below the Rudist limestones in Jamaica. These are at present in the hands of two skilful experts on these organisms, Dr. F. A. Bather, F.R.S., and Professor H. L. Hawkins, F.G.S., whose considered opinion on these fossils will be of great value in the estimation of the horizon of the Jamaican Rudist beds. The preliminary examination of these seems to lend support to the view that the limestones are of exceptionally late Cretaceous age.

The single echinoid from the Barrettia bed of Green Island is said to have all the features of *Lanieria*, without any of the essential structure of that genus. It cannot at present be placed in any known genus.

EXPLANATION OF PLATES.

Plate XVIII.

Fig. 1.—*Barrettia* cf. *multilirata*; Whitfield; var. *conica* nov. Upper Cretaceous. Haughton Hall, near Green Island, Western Jamaica. Specimen with upper valve in place. One-half natural size. 1*a*. View of top valve. 1*b*. Side view of both valves conjoined. Author's collection.

Plate XIX.

Fig. 1.—*Barrettia* cf. *multilirata*; Whitfield; typical form (?). Upper Cretaceous. Haughton Hall, near Green Island, Western Jamaica. Specimen with upper valve in place, the upper valve partly crushed into the visceral cavity. Above the centre of the top valve are seen the two

oval foramina corresponding to the first and second pillars of the living chamber. Near the right-hand top corner part of the lid is broken away, showing the pits produced by the monoliform rays and the concentric shelly walls. Rather under one-half natural size. Author's collection.

Fig. 2.—*Barrettia* cf. *monilifera*; Woodward. Same locality. A young specimen with the upper valve in place, partly crushed into the visceral cavity. Rather over one-third natural size. 2*a*. Top view; at the bottom of the figure is seen the embayment of the margin of the shell. 2*b*. Side view of both valves conjoined. The decoration of lid and sides is well seen on young examples such as this one. Same collection.

Plate XX.

Fig. 1.—*Barrettia* cf. *monilifera*; Woodward. Upper Cretaceous. Haughton Hall, near Green Island, Western Jamaica. Specimen of the lower or conical attached valve viewed from above. The lid is missing and the living chamber has been cleaned out. Around the living chamber are seen the pits of varying size and depth into which shelly processes from the under side of the top valve fitted. Near the left-hand side a portion of the top valve remains. Slightly over one-third natural size. Author's collection.

Fig. 2.—Same species. Same locality. Specimen with both valves conjoined, the central part of the lid almost completely crushed into the living chamber, viewed partly from above and partly from the side. The top lid is very thin and is weathered away in places, especially near the right-hand top edge of the figure, where the moniliform rays like strings of beads can be seen. In other parts the saucer-like depressions on the surface of the top valve are visible. Towards the lower part of the figure the top lid is partly grown over by oysters. Slightly under one-third natural size. Same collection.

Fig. 3.—*Barrettia* cf. *multilirata*; Whitfield; var. *cylindrica* nov. Same locality. Specimen with both valves conjoined, part of the lid broken away at the top right-hand edge. Rather over one-third natural size. Same collection.

Fig. 4.—*Cardita* (*Venericardia*) cf. *subcomplanata*; d'Archiac. Same locality. Right valve. Natural size. Same collection.

Fig. 5.—*Avellana* (*Eriptycha* ?) cf. *decurtata*; Zekeli. Same locality. Natural size. Same collection.

The Traprain Law Phonolite.

Part I: Nepheline, Analcite, Sodalite, and Olivine in the Traprain Law Phonolite.

By A. G. MacGregor, M.C., B.Sc.

Part II: Analysis of the Traprain Law Phonolite.

By F. R. Ennos, B.A., B.Sc., A.I.C.

Part I.

A RE-EXAMINATION of the trachytoid phonolite of Traprain Law was undertaken on the suggestion of Mr. E. B. Bailey, in order to determine the characteristics and mode of occurrence of the nepheline contained in it. The slides examined were those of the Geological Survey collection and nine new ones specially cut from material recently obtained. During the course of the examination sodalite and olivine were detected in the rock. These minerals have not been mentioned in previous accounts of

5 4

3 2

C. T. T. photo.

BARRETTIA (about $\frac{1}{3}$ nat. size). GASTEROPOD AND LAMELLIBRANCH FROM THE BARRETTIA BED (nat. size). Jamaica.

To face p. 514.]

the petrography of Traprain Law, and sodalite seems to have been described in only one other rock from the British Isles (14).[1]

In Traprain Law *all* the isotropic mineral content was previously taken for analcite. Now that some of it proves to be sodalite, the question must be faced, how far the analcite of other Scottish rocks will survive chemical investigation.

After Part I of this paper had been written Dr. Flett very kindly arranged for a re-analysis of the Traprain Law phonolite in the Geological Survey laboratory. Mr. Ennos undertook the work and his results furnish the material of Part II.

Optical Examination.

Nepheline.—During the examination of the slides under the microscope a mineral was noticed to occur fairly abundantly, and with the following characteristics :—

1. *Very low polarization colours.*—Between crossed nicols the mineral had a pale indigo-blue-grey colour. This polarization colour was decidedly lower than that of the felspars, and by means of it the larger patches of the mineral could be picked out fairly readily, after some practice, with the 1 inch objective. The smaller patches were located by a careful examination with the $\frac{1}{4}$ in. objective.

2. *Refractive Index*, as shown by the Becke test, decidedly higher than that of the surrounding alkali-felspar laths of the groundmass in contact with it, and approximately the same as that of the balsam of the slide.

3. *Clearage.*—Indications of cleavage were generally present, one fairly well defined, and another much less clear and approximately at right angles to the first. With reference to the better defined cleavage the mineral showed straight extinction and negative character.

4. *Decomposition.*—The felspars of the groundmass were in general made cloudy by brown powdery decomposition products, but this was not the case as regards the mineral in question, which stood out, in ordinary light, clear, colourless, and transparent among the cloudy felspar laths. Very occasionally isotropic material occurred in such a way that it might be interpreted as replacing this mineral (nepheline). Tiny very sporadic fibres (a zeolite ?) could often be seen in the mineral.

5. *Habit.*—In nearly every case the mineral showed ophitic relations to the felspar laths of the groundmass, and good idiomorphic outlines were never seen. Very occasionally the mineral was included as small irregular patches within the felspar phenocrysts. Occasionally approximation to squarish rectangular outlines was seen, but idiomorphism was never complete. Exceptionally there was a doubtful suggestion of a felspar lath moulded on the mineral.

6. *The size of the patches* ranged from those hardly determinable with a $\frac{1}{4}$ in. objective, to irregular patches about the order of 0·6 mm. The size varied greatly even in the same slide.

7. *Interference figure.*—Many attempts were made to get an interference figure from the mineral, but the best were very ill-defined, and it was even difficult to decide whether a biaxial or a uniaxial figure was being dealt with. In some cases the figure could be doubtfully interpreted as a very broad, ill-defined uniaxial black cross giving negative character with the gypsum plate. The mere failure to give a distinct figure, when combined with the very low double refraction, suggested a distinction between the mineral and a felspar.

From the above characteristics it was suspected that the mineral was nepheline.

[1] Figures in parentheses refer to the Bibliography at the end.

Sodalite and Analcite.—There was also noticed under the microscope the abundant isotropic material previously referred to as analcite in descriptions of the rock. Its characteristics were :—

1. *Isotropic.*
2. *Refractive Index* much lower than that of the surrounding alkali felspar laths of the groundmass, and very much lower than that of the balsam of the slide.
3. *Cleavage*, when present, very ill-defined.
4. *Decomposition.*—Among the groundmass felspar laths, with their brown powder of decomposition products, the mineral stood out clear and colourless.
5. *Habit.*—Crystal outlines entirely absent. The isotropic material occurred typically wedged in between the felspar laths of the groundmass as abundant small patches, often of roughly triangular shape, owing to the straight bounding edges of the felspars : sometimes in larger roundish patches with ophitic relations to the felspars : exceptionally as a small vein cutting across the rock, moulded on the idiomorphic terminations of felspar laths. The general mode of occurrence did not suggest derivation from nepheline.
6. *Size of patches.*—The smaller were about 0·18 mm. by 0·08 mm. The larger roundish patches ranged up to about 0·5 mm. by 0·4 mm. The veins were about 0·4 mm. broad.

From the above characteristics the isotropic material might be analcite or sodalite, or it might be made up of both.

Olivine.—Besides the green pleochroic augite described by Dr. Hatch in his account of the rock (5), a mineral was noticed with the following characteristics :—

1. *High polarization colours.*—Blues, greens, and reds of the second order and higher.
2. *Refractive Index.*—High.
3. *Cleavage.*—One very pronounced somewhat irregular cleavage or parting, and sometimes another much less well defined but more regular and at right angles to the general direction of the first. Also irregular cracks. Extinction almost always parallel to the cleavages. The optical character of the more regular cleavage zone was positive.
4. *Decomposition.*—Often clear and undecomposed, colourless to very pale yellow in parallel polarized light, and not pleochroic. In other cases wholly or partly altered to a pale or olive-green serpentinous substance with very low polarization colours. Olivine-shaped pseudomorphs common, occasionally in a more decomposed part of the rock replaced by a red-brown or yellowish transparent mineral. Serpentinization started along the cracks and cleavages with some formation of iron ores. (The pleochroic green augite of the rock was almost invariably fresh and undecomposed.)
5. *Habit.*—The mineral occurred in two ways—(*a*) As small crystals and granules in the groundmass, always with slightly ophitic relations to the felspar laths, the majority with quite irregular outlines, but many showing the characteristic shape of olivine. (*b*) As larger scattered patches with ophitic relations to the felspars. The components of each large scattered patch were shown to be in optical continuity by the cleavages and extinction. The ophitic relations were as striking as those commonly shown by augite in dolerites.
6. *Size of crystals.*—Irregular grains up to about 1 mm. in length. Shaped olivines up to about 0·3 mm. by 0·18 mm. Ophitic patches extending through an area as large as 1·1 mm. by 0·9 mm.
7. *Interference figures* were biaxial and showed a very large optic axial angle, but in some cases it seemed possible to determine the optical character as definitely negative.
8. In the crystals with the characteristic shape of olivine there was a very well-defined but irregular parting more or less parallel to (001), and sometimes

a faint but irregular cleavage parallel to (010). Nearly all such crystals extinguished parallel to the cleavages.

From the above characteristics the mineral was suspected to be olivine in spite of the unusual ophitic mode of occurrence. The mineral occurred abundantly in the rock, but not so frequently as the pleochroic augite. In a few slides it was absent.

Microchemical and Chemical Examination.[1]

Nepheline.—In order to test the supposed nepheline, three slides were subjected to the same microchemical staining process employed by Dr. Hatch (4 and 5). Over twenty patches of the supposed nepheline were noted and their positions recorded both by sketches and by co-ordinates on the grid engraved on the fixed stage of a Dick microscope. Each slide was then cleaned with benzol and covered with a few drops of concentrated hydrochloric acid. Five minutes acid treatment was found to be quite sufficient. The slide was then carefully washed for about twenty minutes in a very gentle stream of running water in a flat dish, treated with a solution of fuchsine, and again carefully washed. *Every* marked patch of supposed nepheline was stained and stood out distinctly from the unaffected felspars. It was found that staining was unnecessary, as the gelatinized patches could be clearly seen after the acid treatment and washing. An *even cleaner* test was made in the case of two slides by more prolonged treatment with acid, when the nepheline was entirely removed and a hole left with the shape of the original nepheline patch.

This test confirmed the presence of nepheline.

Analcite and Sodalite.—Isotropic patches were observed to stain in the slides primarily used to test for nepheline, and some of the isotropic material was seen to be attacked by the acid much less readily than the nepheline. In order to test further the nature of the isotropic material, patches were marked as in the case of the nepheline, and the slide was covered with a few drops of pure dilute nitric acid and silver nitrate for about twenty minutes, and then carefully washed and exposed to sunlight. Under the microscope different patches of the marked isotropic material were now seen to present quite distinct characters. Some had been highly corroded and were crowded with small black grains, especially at the edges, and in consequence at once stood out and caught the eye. Others were much less corroded, but had acquired a very striking system of small reticulated cracks, quite independent of cleavage (when the latter could be made out). These cracks were just visible with the 1 in. objective. The cracked patches had no deposit of black grains. Further, with the naked eye the surface of the slide could be seen to be covered in parts with

[1] As explained above, the chemical analysis of the rock by Mr. Ennos is reserved for Part II, where it is accompanied by a discussion of mineral proportions.

a very finely granular purplish deposit, which became dark brown on exposure to bright sunlight. This fine powdery deposit was traceable to the highly corroded patches as a source. By treatment of the slide with aqueous ammonia, all the dark particles were removed. Hence it was concluded that silver chloride had been formed at the expense of some of the isotropic patches, which were thus shown to contain chlorine.

Two slides of ditroite were then cut from a hand-specimen with blue sodalite apparent to the naked eye, and were similarly treated. The sodalite patches were corroded and became crowded with dark grains, and there was seen on the slides a purple deposit, precisely the same as that already described, which darkened in sunlight. The spreading of this purple deposit from the large sodalite patches was actually observed with a hand lens during the action of the nitric acid and silver nitrate, and it was found impossible to prevent this taking place to some extent.

In contrast to the phenomena shown by the ditroite, slides of teschenite from the island of Inchcolm and from Crossall Hill, Dalmeny, when similarly treated with nitric acid and silver nitrate, gave no sign of a silver chloride precipitate. Instead, the large analcite patches of these rocks acquired the same reticulated pattern as was observed in some of the isotropic material of Traprain Law. Very dilute nitric acid and silver nitrate gave the best result.

A further test for chlorine in the Traprain Law rock was made as follows. A small fragment of the rock was crushed and repeatedly shaken up with cold distilled water. The filtrate did not react for chloride, thus proving water-soluble chlorine was not present in appreciable quantity. Another chip when powdered and treated with cold dilute nitric acid gave a dense precipitate of silver chloride on adding silver nitrate to the filtrate. This proved acid-soluble chlorine was present.[1]

The only sources of acid-soluble chlorine in an igneous rock are the sodalite group of minerals and sometimes apatite. Only very minute apatite needles were present in the five slides cut from the hand-specimen used for crushing, and could not account for the dense silver chloride precipitate, even on the supposition that all the apatite was chlorine-bearing. (Occasionally larger very sporadic apatites are met with in the Traprain Law rock.) Hence part of the isotropic material was referred to a mineral of the sodalite group.

Because Hillebrand (6, p. 26) states that chlorine is an essential component of noselite (nosean), another rock chip was powdered and boiled with dilute hydrochloric acid. The filtrate when tested did not react for sulphate. This proved that part of the isotropic material was sodalite.

The Inchcolm teschenite, when crushed and tested for chloride, gave no appreciable precipitate of silver chloride. This test, when

[1] See also analysis, Part II.

coupled with the evidence of the peculiar reticulated cracks already mentioned, showed that part of the isotropic material of Traprain Law was analcite.

An especially good example of the joint occurrence of analcite and sodalite was afforded by a vein of isotropic material 0·4 mm. wide, which traversed one of the slides. The differential action of the nitric acid and silver nitrate here showed clearly that the vein consisted chiefly of analcite, but partly of sodalite. Before the microchemical test the presence of only one isotropic mineral was suspected.

It is hoped that the simple qualitative test for chlorine on the rock powder will prove a useful means of detecting the presence of sodalite in any rock, and that further work will show that the reticulated system of cracks is characteristic of analcite among isotropic minerals under the conditions specified above.

Olivine.—The optical characters of the supposed olivine left some slight doubt that the mineral might be an augite. This doubt was removed by marking and drawing as before about fifteen pieces of supposed olivine (crystals with olivine shape, irregular grains, and ophitic patches) in different slides and treating with concentrated hydrochloric acid for about ten to fifteen minutes. In every case the mineral was at first attacked and then entirely removed by the acid. This is characteristic of an olivine not rich in forsterite. The irregular cracks and cleavages were often left running across the space where the mineral had been, owing to the magnetite deposited in them on the commencement of serpentinization. The green augites were unaffected by the acid. The former mineral was thus proved to be an olivine fairly rich in iron.

Note.—For success in all the microchemical work it was found essential to locate carefully and to draw a sketch of each patch of the mineral under investigation, and the other minerals in its neighbourhood, after the cover-glass, but not the balsam, had been removed. Without these precautions it was found extremely difficult definitely to locate portions of the slide seen before the microchemical treatment, owing to movement during removal of the cover-glass, and the changes due to the action of the acid and the absence of the balsam. The stain of fuchsine is not stable in presence of hot balsam, so it is not convenient to replace cover-glasses on slides so stained.

Appendix I.

Notes on Previous Work.

Nepheline.—Dr. Hatch, who discovered that Traprain Law was a phonolite, states in his description of the rock (4 and 5) that he had great trouble in determining the nepheline, but that Rosenbusch, who examined some of the slides, detected small four- and six-sided sections of that mineral.

Analcite.—Dr. Hatch (5) states that analcite and natrolite are present in Traprain Law as alteration products of the nepheline.

In Mr. Bailey's description of the Traprain Law rock (*i*) evidence is given that the isotropic material (described as analcite) is primary in origin.

Sodalite.—Mr. Player's analysis of Traprain Law, given in Dr. Hatch's Edinburgh Royal Society paper (5), does not record chlorine.

Rosenbusch states (13, p. 963) that in the phonolitic rocks the minerals of the haüyne group (which includes sodalite) are always idiomorphic. The mode of occurrence of sodalite in Traprain Law constitutes an exception to this rule.

The only other known occurrence of sodalite in a rock from the British Isles is—as far as I am aware—that noted by Dr. Shand in his paper on borolanite and its associates in Assynt (14). Here, in a rock which he calls assyntite, he found idiomorphic sodalite, showing sections of the rhombic dodecahedron, and enclosed by all later minerals. He identified the mineral by its low refractive index and isotropism, and by the chlorine reaction of the rock. He says there is no evidence to justify calling the mineral haüyne or nosean in preference to sodalite. The rock reacts strongly for chlorine and only very faintly for sulphuric acid. An analysis of assyntite has been published by Mr. A. Gemmell (3).

Olivine.—References to the occurrences of olivine in phonolites will be found in Rosenbusch's classical work (13, pages 968, 969, 974) and in the bibliography on pages 952 et seq. of the same volume. I have consulted the papers by A. von Lasaulx (7), by H. Möhl (10), and by P. Marshall (9) therein mentioned, but in no case could I find a record of ophitic olivine.

Lady McRobert (8) describes an augite-olivine-trachyte from the Mid Hill, Eildon Hills, where the olivine is represented by occasional yellow and red-brown pseudomorphs. She says the rock closely resembles that of Traprain Law, but although expecting to find nepheline in the Mid Hill rock, she could not detect it by optical or microchemical methods.

Appendix II.

The Historical Interest of the Traprain Law Phonolite.

Traprain Law has considerable interest in petrological history, as it was, I believe, the second instance in which nepheline was found in a "Palæozoic volcanic rock",[1] and it therefore formed one of the important links which strengthened the chain of evidence, proving that there is no essential difference between the so-called palæo-volcanic and neovolcanic rocks of the continental geologists. O. A. Derby (2) discovered in Brazil the first known occurrence of nepheline and leucite in palæozoic volcanic rocks.

Rosenbusch's examination of Derby's and Hatch's Palæozoic phonolites must have convinced him that he had been right in saying in the 1887 edition of his textbook (11), that to geological age there had previously been attributed a more important influence on the structural and mineralogical forms of eruptive rocks than was

[1] "Palaeovulkanisches Gestein." The fact that the Traprain Law phonolite is actually an intrusion does not affect the argument.

its due. He had come to this conclusion although at that time palæovolcanic equivalents of the elæolite-syenites were unknown. Subsequent editions of his great work mention the Palæozoic phonolites of Brazil and Traprain Law, and he gradually discards the age factor in his classification, stating definitely in his 1896 edition (12) that he recognized that it had no real significance in classification. In the 1908 edition (13) he concludes that this fact is widely recognized because "it has occurred to no geologist to give a separate name to the palæozoic phonolites, leucitophyres, etc."

Appendix III.

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In conclusion I would like to thank my colleague Mr. E. B. Bailey, and Dr. R. Campbell, of Edinburgh University, for their help and advice in the preparation of this paper.

Part II.

The chemical analysis (I) of the Traprain Law phonolite was made in the laboratory of the Geological Survey. For purposes of comparison, the former analyses by J. H. Player (II),[1] and the partial analysis by W. Pollard (III),[2] are also given.

[1] *Trans. Roy. Soc. Edin.*, vol. xxxvii, 1892, p. 125.
[2] "The Geology of East Lothian": *Mem. Geol. Surv.*, 1910, p. 130.

	I.	II.	III.
SiO_2	56·89	56·8	—
TiO_2	·33	·5	—
Al_2O_3	19·11	19·7	—
Fe_2O_3	2·04	2·2	—
Cr_2O_3	nt. fd.	—	—
FeO	3·44	3·5	—
MnO	·18	·2	—
(CoNi)O	nt. fd.	—	—
CaO	2·15	2·2	—
BaO	·01	—	—
MgO	·35	·4	—
K_2O	6·35	7·1	6·41
Na_2O	6·88	4·3	6·79
Li_2O	nt. fd.	—	—
H_2O at 105° C.	·54	2·5 (loss on ignition)	—
H_2O above 105° C.	1·68		—
P_2O_5	·15	—	—
FeS_2	·17	—	—
SO_3	trace	—	—
CO_2	nt. fd.	—	—
Cl	·22	—	—
	100·49	—	—
Less O for Cl	·05		
Total	100·44	99·4	—

It will be seen that, with the exception of the alkalies, the new analysis agrees very closely with that of Player. The new figures for potash and soda, which confirm the partial analysis of Dr. Pollard, differ from those of Player, both in the total and in the relative proportions of the two oxides. The only other constituent in which any serious divergence occurs between the two analyses is the alumina, but, after making allowance for the phosphoric anhydride not determined by Player, the discrepancy amounts to only 0·4 per cent. Phosphoric anhydride and chlorine, of which no mention is made by Player, have been found in quite appreciable quantity. Special interest attaches to the determination of these constituents, owing to their importance in the calculation of the amount of sodalite. If the phosphoric anhydride is assumed to be present as chlorapatite, the 0·15 per cent of P_2O_5 found will require 0·02 per cent of chlorine to form $3Ca_3P_2O_8 . CaCl_2$. The remaining 0·20 per cent of chlorine calculated to $3(Na_2O,Al_2O_3,2SiO_2)\ 2NaCl$ gives 2·7 as the percentage of sodalite in the rock.

The mineral composition of the rock has been calculated from the chemical analysis in the following way and the results are appended below. After determining the amounts of ilmenite from the titania and chlorapatite from the phosphoric anhydride, the residual chlorine is allotted to sodalite. Total potash is calculated as orthoclase, and water above 105° C. as analcite. The soda remaining after allowing for that in sodalite and analcite is divided between albite and nepheline, the relative amounts of these being determined by the silica available after all other silicates have been satisfied. As

some alumina is still unaccounted for, this is given the requisite amounts of lime and silica to form anorthite. Ferric oxide is then combined with the corresponding amount of ferrous oxide for magnetite. The residual lime, together with ferrous and magnesium oxides in the proportion in which these two are left, yield the metasilicate diopside, while the rest of the ferrous oxide and magnesia enter into combination with silica as the orthosilicate olivine.

By the above method a somewhat conventional representation of the mineral composition of the rock is obtained. It is probable that the figure for analcite is too high, owing to the presence of other hydrous minerals. Further, there is no soda available for the calculation of the amount of alkali-bearing pyroxene present. Diopside, as such, does not occur in the phonolite.

Orthoclase	K_2O, Al_2O_3, $6SiO_2$	37·58
Albite	Na_2O, Al_2O_3, $6SiO_2$	20·07
Anorthite	CaO, Al_2O_3, $2SiO_2$	3·19
Nepheline	Na_2O, Al_2O_3, $2SiO_2$	4·23
Analcite	Na_2O, Al_2O_3, $4SiO_2$, $2H_2O$	20·50
Sodalite	3 (Na_2O, Al_2O_3, $2SiO_2$), 2NaCl	2·71
Diopside	CaO, SiO_2 ·2·74 MgO, SiO_2 ·50 FeO, SiO_2 2·45	5·69
Olivine	$2MgO$, SiO_2 ·26 $2FeO$, SiO_2 1·51	1·80
Magnetite	FeO, Fe_2O_3	2·97
Ilmenite	FeO, TiO_2	·62
Chlorapatite	$3Ca_3P_2O_8$, $CaCl_2$	·35
Pyrites	FeS_2	·17
Moisture	H_2O	·54
Total		100·42

The Lower Carboniferous Rocks of Cumberland.

By K. W. Earle, M.Sc., F.G.S.

On glancing over back numbers of the Geological Magazine after eight months' residence abroad, I have been much interested to find a paper by Mr. C. Edmonds on the Carboniferous Limestone of West Cumberland.[1]

I myself worked in this district in connexion with a more ambitious paper on the whole of the limestone series from Penrith via Caldbeck to Egremont, which paper formed the subject of a communication to the Geological Society last November. It is needless to say that at the time of my work I had no idea there was an independent observer in the field, or I should not have devoted much time to his area. Such duplication of field work, though regrettable, is perhaps, however, not entirely wasted if the second observer is able—as I am in the present case—to confirm the conclusions of the first by independent mapping.

[1] Geol. Mag., Vol. LIX, 1922, pp. 74 and 117.

In view of the publication of Mr. Edmonds' paper and the refusal of the Geological Society to publish mine, it is doubtful if my paper will ever be printed *in extenso*. I may perhaps, therefore, be allowed to offer here a few remarks both on the area described by Mr. Edmonds, and on the larger area described as a whole by me.

In the first place I should like to congratulate Mr. Edmonds on the thoroughness of his field work and on the completeness of his faunal collections in a district where the chief outcrops consist of gigantic unscaleable quarries, either abandoned and filled with water, or rendered dangerous of approach for 5½ days in the week by incessant blasting.

The size of the area covered by my paper, and the rather abrupt termination of my work in 1920, did not leave me as much time for the Egremont area as I should have liked, and my faunal collection is nothing like as complete as Mr. Edmonds'. I must confess, for example, that though I was always on the look out for it, the *Girvanella* band escaped my notice, which led to my placing the junction between D_1 and D_2 rather lower than is evidently the case. In the area north of Cockermouth, the *Girvanella* band occurs immediately below a thick sandstone, undoubtedly the representative of the Orebank Sandstone of the Egremont district. In the latter area, however, the sandstone no longer forms a natural base to D_2; it has, in fact, transgressed across some 200 feet of the limestone, till it rests only 80 feet below the Millstone Grit, just as the Orton-Ashfell Sandstone transgresses across the zones in the North-West Province.

In the same way the Millstone Grit episode enters much earlier in the Egremont area, probably earlier than anywhere else in England.

Mr. Edmonds notices the absence of a true Bryozoa Bed at the base of D_1 in the Egremont area. I called attention in my paper to the marked contrast between this and the Cockermouth-Bridekirk-Uldale district, where the band attains a greater thickness than probably anywhere else in the country and has a very abundant fauna.

I find no reference in the paper, however, to the well-marked *Chonetes comoides* band of Professor Garwood, which occurs well up in D_1. This is seen at Pardshaw Crags, Scalesmoor, and in the cutting in Yeathouse Quarry. The *Chonetes comoides*, which occurs up to a large size, is associated with *Cyathophyllum murchisoni*, *Productus hemisphericus*, *Dibunophyllum*, and a few *Cyrtina septosa*. This band is one of the most constant throughout the whole limestone area, and can be traced at intervals all the way from Penruddock via Caldbeck, Bothel, and Cockermouth to Egremont. It is possible that it forms a band in Mr. Edmonds' "White Beds", as *Lonsdaleia duplicata*, mentioned by him as being characteristic of the lower part of those beds, does occur in the *Chonetes comoides* band. There also occurs an early form of

Lonsdaleia floriformis, and this fossil is still more characteristic north of Cockermouth, indicating that this species entered the Carboniferous seas from the west, arriving much earlier here than in the North-West Province.

With regard to the lowest beds exposed in the Egremont area, I collected from the Longlands (east) spoil-heap an alga closely resembling *Girvanella* externally, but identified by Professor Garwood as *Spongiostroma* round a central nucleus of *Mitcheldeania*. By analogy with the North-West Province, this should indicate the base of S_1. Apart from the evidence afforded by this isolated specimen, I agree with Mr. Edmonds that the lowest horizon developed in the area is the *Nematophyllum minus* subzone (S_2)—a particularly fine development of the bed being seen in the spoil-heap at the Winscales mine, where the iron ore is won from the limestone through a capping of 950 feet of drift, St. Bees' Sandstone, and Brockram.

The *Nematophyllum minus* subzone is, in fact, the lowest zone definitely recognized anywhere between Penrith and Egremont, though there are indications that the *Michelinia* zone (C_2) was once exposed at Dacre (Penrith). It is probable, from a consideration of the radial dip (which is little more than sufficient to carry beds of D_1 age over the present summit of Carrock Fell) and of the faulting, that beds of D_1 age once enveloped the whole Lake District massif, though it is remarkable that, with the single exception of the outlier at Wilton Fell (Egremont)—of S_2 age—no relic has yet been discovered of this former Carboniferous mantle.

There would appear to be a rapid thinning out of the lower zones between the Dalton-in-Furness area, where all the horizons from the *Athyris glabristria* zone upwards are developed, and the Egremont area 20 miles to the north, and it would be an interesting study, if possible, to trace this thinning out by means of borings through the superficial Triassic deposits.

No true basal conglomerate, nor any Polygenetic Conglomerate occur at the base of the limestone in the Egremont area, the limestone resting directly across the edges of the Skiddaw slates. The Polygenetic Conglomerate is, however, well exposed at Woodhall (Cockermouth), Uldale (Caldbeck), and Holghyll (Penruddock). Its irregularity in distribution, thickness, etc., and its high angle of dip, in marked unconformity with the gently dipping limestones above, lead to the conclusion that it was no part of the Carboniferous submergence proper; considering, however, the vast amount of erosion necessary to produce the constituent material since Silurian times, and the inclusion of fragments of Shap igneous rocks, it is probable that it was formed as a continental deposit of Upper Old Red Sandstone age, a conclusion reached by other writers on the subject.

The other features brought out by mapping the limestones between Cockermouth and Penrith are chiefly concerned with local variations in the faunal assemblages, though generally speaking the subzones

and bands established by Professor Garwood in the Shap area are recognizable throughout the district. The various beds are often shifted laterally, cut out, or repeated by a complicated system of dip, strike, and block faulting. Mr. Edmonds has promised to discuss the earth movements in the Egremont area in a subsequent paper; as they are somewhat similar to those in the northern limestone area, they need not be discussed here.

REVIEWS.

AGE AND AREA: A STUDY IN GEOGRAPHICAL DISTRIBUTION AND ORIGIN OF SPECIES. By J. C. WILLIS, with chapters by HUGO DE VRIES, H. B. GUPPY, E. M. REID, and JAMES SMALL. 8vo, x + 260 pp. Cambridge University Press, 1922. Price 14*s.* net.

BY "Age and Area" Dr. Willis means that the area occupied by a given species is proportionate to its age. Area is calculated by taking the greatest distance from the assumed or inferred centre of dispersal as the radius of a circle, that circle being regarded as the area even though the distribution of the species within it be sporadic. Age is the time that has elapsed from the entry of a species into the district under consideration. If the district be an island (to take a simple case) the species may have entered from a neighbouring district where it previously existed, or it may have originated as a new species within the island itself; the centre of dispersal then is, in the former instance, the point of entry, in the latter instance the point of origin, and age is dated from entry or origin respectively. The general statement is to be understood as referring to averages of not less than ten species, and those species must be allied. Thus interpreted, the statement is believed to be similarly applicable to genera and to families, and to be equally true whether the district under examination be an island, a continent, a geographical region, or the whole world. Though based originally on the distribution of land-plants, the principle can, Dr. Willis claims, be extended to animals. The animals mentioned are mostly those of land or fresh water, but there seems no reason why marine faunas and floras should not be subject to the same rule.

It would be easy to reel off a long list of exceptions to the statement, even if attention were restricted to species now living. But remembering the careful qualifications by Dr. Willis, and noting the evidence brought forward by him and by others, one can hardly deny the main thesis. The idea is indeed familiar to those of us who were brought up on Lyell's "Principles" (even the early editions) and on Darwin's "Origin of Species", but the merit of Dr. Willis is to have made it more precise by a variety of numerical statements. He goes, however, much further than this, in that from the universality of his rule he draws the conclusion that the extent of

distribution of a species depends, not on any advantage it may be supposed to have over its congeners, as by some ingenious method of seed-dispersal, but solely on the length of time during which the causes of dispersal have operated. Now, since wide dispersal, or its correlative longevity, implies success in life, it follows, on Dr. Willis' reasoning, that success has nothing to do with advantageous or adaptive characters. In other words, all species are equal, and Dr. Willis has no use for Natural Selection. Evolution, according to him, must take place solely through a succession of "mutations" (= saltations), and the direction of evolution must be due to some guiding principle other than the environment.

Some palæontologists may welcome this conclusion, others will incline to oppose it. Mrs. E. M. Reid, who contributes from the palæobotanical standpoint a chapter that in its ease and clarity of style contrasts markedly with the rest of the book, deals with one obvious objection, namely, the extinction of species. The Age and Area hypothesis seems to pass this by too lightly. It assumes that a species originating in, say, Tibet, will go on living and spreading till it has conquered the whole earth. If it at any time become extinct (for even Dr Willis must admit that some species have perished) it will be from "exhaustion of its vitality". But we know that whole floras and faunas have vanished, and that not merely species and genera, but great systematic groups of animals and plants have been exterminated, some in Palæozoic, some in Mesozoic times. We see how at the present day species and genera are exterminated by a change in their physical surroundings, or by the introduction of some actively or passively hostile form of life. We have excellent reasons for our belief that similar changes in the past (a glacial period or the appearance of egg-sucking mammals) have wrought similar havoc. When, then, Mrs. Reid shows us a progressive extermination of older forms as compared with newer throughout Pliocene times, what right have we to assume that this was due to some inherent defect? Must we not rather agree with Lyell that the fluctuations of the earth's surface provide an efficient cause? But if this be admitted, the door is again opened to Natural Selection. Dr. Willis confesses that a newly formed species "will have a most strenuous struggle for existence, *immediately*", but he forgets that this struggle may be renewed by a change in the conditions often of apparently trivial character.

Dr. Willis also seems to overlook the distinction, on which De Candolle, Lyell, and others insisted, between station and habitation. From this point of view it may be said that adaptation has little to do with geographical extension, but is of chief importance in relation to the precise conditions of life. Diversity of conditions may depend but slightly on locality; on a single square foot of sea-bottom, of the present or of past ages, we find creatures that live or lived under most different conditions; and the more we realize those conditions the more we realize the adaptation of

the organism thereto. Such adaptation leads to specialization, and specialization hinders survival when conditions change. It is the simple primitive forms that persist and attain the widest distribution. Age and Area, Size and Space, Rank and Range, and the other artful alliterations not only are consistent with these facts, but are, as Darwin showed (*Origin*, ed. vi, pp. 358–62), their natural corollary.

This review has dealt with one of the chief points raised by Dr. Willis, one that is of particular interest to geologists and palæontologists. There are others that one would like to discuss, but it must suffice to say that those who have leisure and perseverance to grapple with a complicated style will find "Age and Area" a stimulating as well as a provocative book. If it do no more than lead them to re-peruse Lyell and Darwin, it will have served a good purpose.

F. A. Bather.

Geology of the An-Shan Iron Mine District, South Manchuria. By H. Murakami. pp. 53, with xxvi plates, 6 text-figures, and a coloured geological map. Published by the South Manchuria Railway Company, 1921.

THE important iron-ore deposit of An-Shan, now worked on an extensive scale and smelted locally in two blast-furnaces, lies about 56 miles south of Mukden. The formations found in the district comprise only Pre-Cambrian, Cambrian, and Quaternary sediments, with intrusive igneous rocks. The general geology, as well as the character of the ores, show analogies to the Lake Superior district. The Pre-Cambrian formations are divided by the author into two groups, the Green Schist complex and the Hematite-quartz-schist. The latter differs mainly from the taconite series of Michigan in the fact that the siliceous layers consist of coarsely crystalline quartz instead of chert. The iron ore is locally enriched to a high-grade product, but it is now found necessary to concentrate the leaner ores in order to supply the furnaces.

The Cambrian rocks include a basal conglomerate, overlain by quartzites, often ferruginous, and siliceous slates; the Hsiao-fang-shen series at the top includes limestones, and contains *Lingulella*, *Obolus*, *Acrothele*, and the trilobites *Agnostus*, *Ptychoparia*, *Lisania*, *Crepicephalus*, *Asaphiscus*, and *Redlichia*. From a comparison with more complete faunas in other parts of Manchuria, these appear to indicate a Middle Cambrian age. The igneous rocks, which include both foliated and unfoliated granites, appear to be of no particular interest.